AMERICAN SOCIETY OF CIVIL ENGINEERS.

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No. 806.

A STUDY IN THE DESIGNING AND CONSTRUCTION OF ELEVATED RAILROADS, WITH SPECIAL REFERENCE TO THE NORTHWESTERN ELEVATED RAILROAD AND THE UNION LOOP ELEVATED RAILROAD OF CHICAGO, ILL.

By J. A. L. WADDELL, M. Am. Soc. C. E.

PRESENTED FEBRUARY 17TH, 1897.

WITH DISCUSSION.

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Wabash Avenue Extension of the Lake Street line, which forms one side of the Union Elevated Loop Railway, he gave the following list of essentials of elevated railroad construction:

First. Loads.—The loads to be considered are these:

A. Live load.

B. Dead load.

C. Thrust of braked trains, or traction load.

D. Wind load, or in reality an assumed transverse load to provide for sway of trains.

E. Centrifugal loads on curves.

Second.—Designing.

F. Longitudinal girders should have sufficient sectional areas, and should be properly detailed.

G. A proper system of bracing between contiguous longitudinal girders should be provided.

H. There should be a proper connection of longitudinal girders to cross-girders.

I. There should be adequate means of transmitting the thrust of braked trains from longitudinal girders to columns without overstraining the cross-girders.

J. The cross-girders should be properly designed in respect to both sectional areas and deta ls.

K. There should be a proper connection of cross-girders to columns to provide for transmission of both longitudinal and transverse horizontal loads.

L. The sections of the columns should be properly designed to provide sufficient strength to resist direct load, bending from longitudinal thrust, bending from transverse thrust, and, on curves, bending from centrifugal loads.

M. There should be a proper anchorage at the foot of each column to make the latter, as far as strength and rigidity are concerned, absolutely continuous with the pedestal.

N. There should be an adequate wooden floor, effectively attached to the metalwork of the superstructure.

O. The general construction of the entire structure should be as economical as practicable in respect to both quantities of materials and facility in erection, due respect being paid to the more important requirements affecting strength and rigidity.

P. The æsthetics of the design should be considered as much as possible without involving extravagant expenditure therefor.

This list of requirements will be referred to later on in commenting upon the details of existing American elevated railroads.

The immediate prosecution of the Lake Street Elevated work was a fortunate circumstance, as far as the investigations for the Northwestern Elevated were concerned, for it gave the author an opportunity to make certain experiments and researches which he might otherwise not have had, notably in the lines of bearing capacity of Chicago soil, details of structure occupying streets, and cold-pressed threads for bolts.

In these investigations the author has received valuable assistance from Charles V. Weston, Esq., who holds the position of Chief Engineer on the Northwestern Elevated, the Union Loop, and the Lake Street Elevated Railroads, and from Samuel M. Rowe, M. Am. Soc. C. E., who was retained temporarily to aid in the preliminary work.

The design of the Wabash Avenue Extension will be referred to later on; meanwhile the investigations for the Northwestern Elevated will be taken up in their consecutive order.

Before proceeding with these, however, it will be well to give a short description of the road. It starts as a double-track structure from the Wabash Avenue Extension of the Lake Street Elevated at the corner of Fifth Avenue and Lake Street, runs north across the Wells Street Bridge to Michigan Street; thence west to Franklin Street; thence north to Chicago Avenue, where it expands into a four-track structure (leaving the street and running into private property), whence it continues in a northerly and westerly direction to a point on Wilson Avenue between Evanston Avenue and the Chicago, Milwaukee and St. Paul Railway tracks, making the total length of line a little more than 6¼ miles, of which all but 1 mile is four-track structure.

I.—Medium Steel *versus* Soft Steel.

At the outset it was necessary to determine whether it is more economical to use unreamed soft steel at a low intensity of working stress, or reamed medium steel at a higher intensity. This question was quickly settled in favor of the medium steel, which can be strained legitimately 10% higher than the soft steel, and costs prac-

tically the same per pound at the rolling mills. The ratio of weights of structure for designs in medium steel and soft steel is about as 93 is to 100, a saving of 7% in weight of metal in favor of the medium steel. Assuming the price of metal erected to be 3 cents per pound makes the saving in pound price 0.21 cent, while the cost of sub-punching and reaming varies from 0.1 to 0.2 cent per pound, according to the facilities of the bridge shop for doing such work. At present perhaps there is a slight difference in the pound prices erected of soft and medium steel in favor of the former, enough possibly to offset the net saving by reduced weight of the latter, so that, as far as the total cost is concerned, it is immaterial whether unreamed soft steel or reamed medium steel be adopted.

There is another point involved here, however, which is of far greater import than mere economy in cost of erected metal, viz., the proper matching of rivet holes in the component parts of built members. For several years the author has favored the sub-punching and reaming of all metal (although he has not always insisted thereon), not so much for the sake of the somewhat disputed benefit derived from removal of cracked metal by reaming, as for the greater certainty of obtaining properly matched rivet holes. His late investigations in this line, made by examining the shop work of the various bridge manufacturing companies of this country, both personally and through his assistant engineers and inspectors, confirm him to such an extent in this opinion that he is now prepared to make the following statement and to invite both criticism and denial thereof.

All structural metalwork, whether it be medium steel, soft steel, or even wrought iron, should be punched at least $\frac{1}{4}$ in. less than the diameter of the cold rivet and reamed to a diameter $\frac{1}{16}$ in. greater than same; and there is no bridge shop in existence which can turn out truly first-class work without sub-punching and reaming or drilling.

Even when the greatest care is taken in punching the metal of the component pieces of long members, many of the rivet holes will fail to match by as much as $\frac{1}{4}$ in., and the author has within a year or two seen $\frac{3}{4}$-in. rivet holes elongated to $1\frac{1}{4}$ ins., merely to admit the rivets. Where several component pieces containing badly matched rivet holes are placed together and a tapered flexible reamer is used to enlarge the hole sufficiently to admit the rivet, the latter cannot possibly fill completely the irregular hole, and, therefore, if left in the piece, can-

not act effectively. If condemned by the inspector on account of looseness, and then driven out, it will, on account of its crookedness, materially injure the metal about the hole and thus weaken the structure, perhaps doing more damage thereto than would the leaving in of the loose rivet.

The use of a tapered, flexibly connected reamer is all humbug, and is not true reaming at all, but merely a means of making it practicable to get the rivets through badly punched holes that assemble irregularly.

Real reaming can only be done with rigid reamers or drills that remain at all times at right angles to the surface reamed, and cut a cylindrical instead of a tapered hole. Such reamers as these are the only ones that ought to be employed on first-class metalwork, excepting, of course, in confined spaces where they cannot be used, and where the flexibly connected reamer must of necessity be employed.

The author knows well that these opinions are at variance with those of a majority of the manufacturers of structural steel, and it is on this account that he presents them so forcibly.

That many manufacturers are opposed to sub-punching and reaming was shown very clearly at the lettings of the contracts for the Wabash Avenue Extension of the Lake Street Elevated, and for the Northwestern Elevated, one manufacturer going so far as to make a difference of one-third of 1 cent per pound between reamed and unreamed work.

At these lettings good evidence was also given confirming a statement of the author, viz.: "It has been hitherto the general opinion that almost any kind of a structure in respect to design, quality of material and workmanship will suffice for an elevated railroad." One manufacturer remarked to the author in criticism of the plans and specifications submitted to bidders: "Why, your requirements in regard to details and workmanship are as rigid as if you were about to build a railroad bridge." The reply to this was, "Yes. I consider this structure to be just as important as any railroad bridge ever built."

And why should it not be just as important? Are not the live loads thereon more continuously applied, and is not the assumed maximum load very nearly reached many times per day? On these accounts, is it not even more important to make an elevated railroad absolutely

perfect in every detail of design and construction than it is to so make a railroad bridge?

The author is by no means alone in his opinion that nearly all the elevated railroads of this country will, in the not very distant future, have to be replaced, and mainly on account of faulty detailing. Of what the faulty detailing consists will be dealt with further on.

At this point the author wishes to call attention to a very reprehensible practice, which these lettings exemplified quite forcibly, viz., attempting to overthrow the engineer's plans and specifications submitted for tendering. In the case of the Wabash Avenue Extension letting a most determined but unsuccessful effort was made to alter the author's plans, so when the specifications for the Northwestern Elevated were drawn, the following clause was inserted with the permission of the president of the company:

"All work herein outlined is to be done in strict accordance with the following specifications, the accompanying plans, and such instructions as may be given from time to time by the company's engineers. Bidders are hereby warned that they will be held strictly to the spirit of these specifications, and that it will be bad policy for any one to bid with the expectation that concessions will be made after the contract is closed, in order that the work may be cheapened; for while the company's engineers desire at all times to aid the contractors in every legitimate manner to do their work expeditiously and economically, at the same time they have given these plans and specifications the most thorough consideration, and know exactly what they need in respect to both design and quality of materials and workmanship. On this account bidders are respectfully requested not to complicate their tenders by putting in alternative bids based on proposed changes in either plans or specifications; because such alternative bids will not be considered."

The result of the insertion of this clause was rather amusing, for attempts were made to overthrow not only the plans, but the specifications also. However, but little difficulty was encountered by the engineers in throwing out all alternative bids; and the contract was let to parties who were willing to tender without suggesting changes in the plans and specifications submitted to the bidders.

Another question that came up at these lettings was that of using acid or basic open-hearth steel. Preference was given to the former in the specifications, but such evidence was submitted to the engineers as to convince them that the basic product can be made as satis-

factory as the acid, and at a trifle less cost; consequently, it was adopted. Since then, however, the reports of the company's inspectors indicate that the basic steel is not quite so uniform in quality as the acid; and that it may prove advisable in future specifications for basic medium steel to reduce the average ultimate stress limits from 64 000 lbs. to 61 000 lbs. per square inch.

It appears to the author that the general adoption of basic open-hearth steel is fast tending to the employment of soft steel for bridges. As far as short and medium spans are concerned, this is all right, but it is the opposite for long spans, especially for very long ones, where the dead load is the ruling factor in proportioning the members. Perhaps in the near future some alloy of steel, such as nickel steel, can be made cheaply enough to warrant its use for very long span bridges.

II—Weights and Dimensions of Motor Cars and Trailers.

After due deliberation it was decided to make both the motor cars and the trailers 40 ft. long out to out, and to carry each car on four

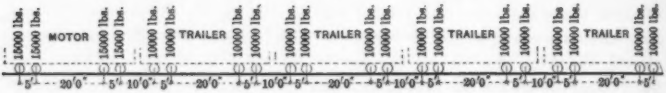

Fig. 1.

axles, the weight of a loaded motor car being 60 000 lbs., and that of a loaded trailer 40 000 lbs. The distribution of this live load is shown in Fig. 1.

III.—The Best and Cheapest Kind of Portland Cement to Adopt, and the Best Proportions for Concrete Made with Same.

This investigation was made by Samuel M. Rowe, M. Am. Soc. C. E. As a result thereof the author has modified his standard specifications for cement so as to read thus:

"All cement used in the work shall be Portland cement of the very best quality obtainable, equal in every particular to the best brands of American manufacture. It shall be ground so fine that at least ninety-seven (97) per cent. in weight will pass a standard sieve of five thousand (5 000) meshes to the square inch, and so that at least ninety (90) per cent. will pass a standard sieve of ten thousand (10 000) meshes to the square inch.

"When moulded neat into briquettes and exposed three (3) hours, or until set, in air and the remainder of twenty-four (24) hours in water,

it shall develop a tensile strength of from one hundred (100) to two hundred and fifty (250) pounds per square inch.

"When moulded neat into briquettes, and after exposure of one (1) day in air, and six (6) days in water, it shall develop a tensile strength of from two hundred and fifty (250) to five hundred (500) pounds per square inch; and after exposure of one (1) day in air, and twenty-seven (27) days in water, it shall develop a tensile strength of from four hundred (400) to six hundred (600) pounds per square inch.

"It shall be an eminently slow-setting cement, must develop its strength gradually, and must show no drop therein. When moulded into pats with thin edges, and either left on glass or not to set in water, said edges must show no signs of checking.

"Briquettes mixed in proportion (by weight) of one (1) part cement to three (3) parts sand, and kept one day in air and the remaining time in water, shall show a tensile strength of from one hundred (100) to one hundred and fifty (150) pounds per square inch after seven (7) days, and from one hundred and fifty (150) to two hundred and fifty (250) pounds per square inch after twenty-eight (28) days.

"In any case the cement adopted must be first approved by the Chief Engineer."

The proportions of Empire or Aalborg cements, which were the brands adopted for the Northwestern Elevated Railroad pedestals, used in making concrete, are:

One part by volume of cement.
Three parts by volume of sand.
Six parts by volume of graded broken stone.

Unless the stone be of several graded dimensions, so as to reduce the proportion of voids to a minimum, its proportion in the concrete should be reduced to five; for while these brands of cement will stand a three-to-one dose of sand, the resulting mortar will not fill completely all the voids in the stone at one, three and six, unless the grading of the stone be done very carefully, and unless the various sizes of stone be thoroughly mixed.

For concrete for bridge pier caissons, using these brands of cement, the author would recommend the following proportions:

One part by volume of cement.
Three parts by volume of sand.
Five parts by volume of broken stone.

In case, however, the concrete be deposited under water or in places where special strength and solidity are required, the proportions should be changed to one, two and four.

IV.—The Best and Cheapest Kind of Metal Paint to Adopt.

Mr. Rowe conducted this investigation also, but unfortunately was not able to complete his experiments. He has promised to give in his discussion his results as far as they go. It was decided to use for the Wabash Avenue Extension Eureka paint, and the National Paint Company's No. 31 for the Northwestern Elevated. In another structure, if the author could have his own way in respect to paint, he would give the metal a good coat of boiled linseed oil at the mills before it is exposed to the weather, one priming coat of Eureka paint at the shops, while the metalwork is still under shelter, and two coats of first-class iron oxide paint after erection.

V.—Prices of Timber F. O. B. Cars Chicago.

This investigation was made in order to determine what kind of timber to adopt, and whether it be advisable to specify all heart or a certain portion of sap, the result being that it was decided to use the best quality of long-leaf southern yellow pine entirely free from sap. This question of timber will be further treated in Section 12.

VI.—Best and Most Economical Span Lengths.

This question was investigated very exhaustively, considering every item of expense, including not only cost of metal in place, but also that of concrete, excavation, back-filling and pavement; also the possibility of expense for the moving of water pipes and other conduits. The investigation showed that for plate-girder construction through private property the economic span length is about 40 ft., while for construction in the street it varies from 47 to 50 ft., or even 3 or 4 ft. more in case of cross-girders spanning wide streets from curb to curb.

The theory of true economy in elevated railroad designing, as far as length of bays is concerned, is simply this: "The cost of the longitudinal girders should be, as nearly as may be, equal to the cost of the bents and their supporting pedestals, in case of doubt adopting the longer span."

VII.—Four-Column *versus* Two-Column Structures.

Detailed estimates of cost show that as far as economy is concerned there is but little, if any, difference between these two styles of bent.

Whether the total cost of the four-column bent will exceed that of the two-column one for a four-track structure depends upon the various schedule prices for metal, concrete, excavation, paving, etc., as well as upon the character of the soil. As there is no great difference in the cost of these two types of structure, and as the four-column bent is decidedly the more rigid of the two, it was adopted wherever practicable. Fig. 2 gives a general elevation and plan showing the steelwork. Cantilevering an entire train load beyond the exterior column of a two-column bent is not conducive to rigidity, but this is the only method that will bring the cost as low as that of the four-column bent.

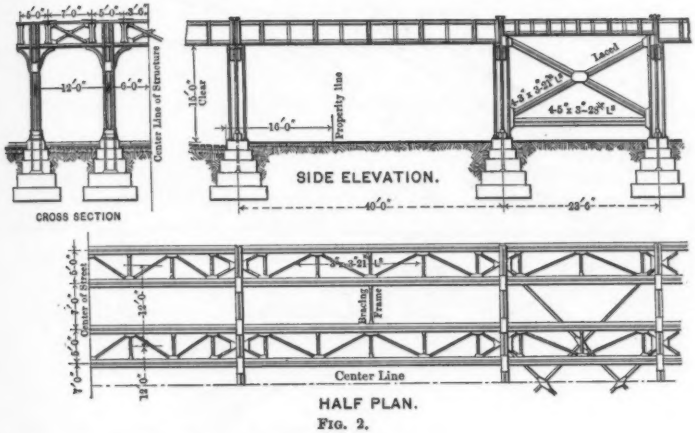

FIG. 2.

VIII.—BRACED TOWERS *versus* SOLITARY COLUMNS.

Where an elevated railroad occupies private property and crosses the streets by spanning from curb to curb, it is practicable to use braced towers and thus stiffen the structure and check vibration; and, moreover, this arrangement is very economical.

For the Northwestern Elevated, upon which it is proposed to run trains at a speed of 40 miles per hour on the inner tracks between the inter-track stations, which are situated about a mile apart, the consideration of the extra rigidity afforded by the braced towers is quite important. It was therefore decided to use both longitudinal and transverse sway bracing forming braced towers spaced about 150 ft. apart (or two towers per block), and to use the transverse sway brac-

ing on all bents on curves, wherever practicable. Fig. 3 gives the details of the longitudinal sway bracing for a 23½-ft. span.

Two only of the three spaces between columns are to have trans-

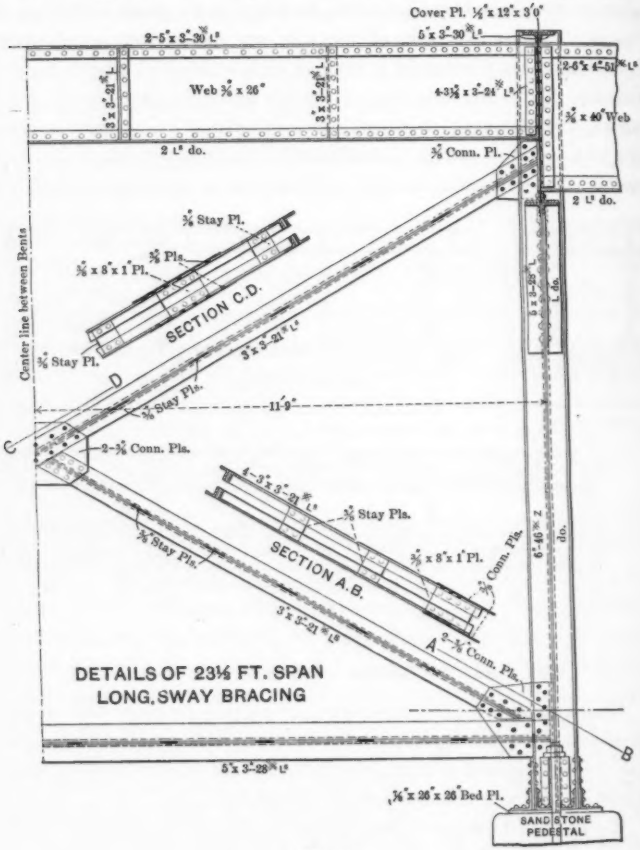

FIG. 3.

verse sway bracing, thus leaving a longitudinal passage-way for wagons at the center of the structure.

The saving in weight of metal per lineal foot of four-track structure on tangents by adopting braced towers instead of solitary columns was found to be about 140 lbs., or nearly 9% of the total weight.

IX.—The Best Weight and Dimensions of Track Rails.

After thorough investigation it was decided to adopt, as the best and most economical section, an 80-lb. rail, 5 ins. high, with vertical sides, and containing 45% of its metal in the head.

X.—Best Arrangement and Dimensions of the Wooden Floor.

The result of the investigation on this subject was, for longitudinal girders spaced 5 ft. centers, the adoption of 6 x 8-in. ties laid flat and spaced 14 ins. centers; 6 x 6-in. inner guards and 6 x 8-in. outer guards on edge, all guards being fastened by soft steel bolts with pressed threads, and connections to the metalwork being made by means of hook-bolts. Fig. 4 illustrates the track system.

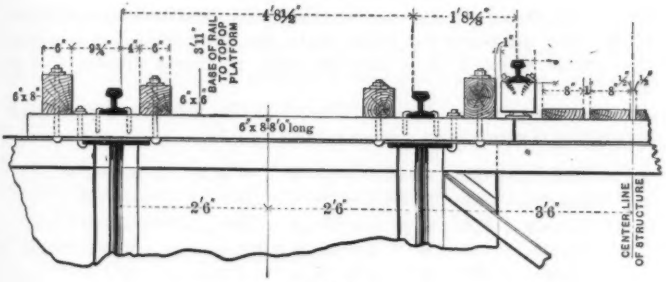

Fig. 4.

XI.—Collection of Data of Various Kinds Concerning Elevated Railroads.

The results of this investigation, made by the author and his assistants by examining the principal elevated roads of the East and those then in operation in Chicago, as far as the designing of the metalwork is concerned, amount simply to the accumulation of a great mass of information exemplifying "how not to do it."

Such negative data are, of course, useful; but, if a properly designed and constructed road in operation could have been examined, the information accumulated would have proved much more valuable.

Much useful information, however, was obtained upon such matters as track, stations, signals, etc., by the examination of existing elevated railroads.

XII.—Treated *versus* Untreated Timber for Tracks and Platforms.

After considerable investigation it was decided to preserve the timber by the vulcanizing process. The following extracts from the author's report to the company on this subject may be of interest.

"Unfortunately, the only vulcanizing works in this country are located in New York City; consequently, the freight rates on vulcanized timber delivered at Chicago are high, the average price for such timber as we need being about $32 per thousand delivered at site, while the untreated timber would cost only $18 per thousand. It will cost about $6 per thousand additional to put the timber in place.

"Vulcanized timber has been used on the New York Elevated Railroads for twelve years without showing any signs of material deterioration, and the chances are that it will last fully twenty-five years.

"Our investigations lead us to the conclusion that it costs about $1 per tie to replace ties in the track without interfering with the traffic, over and above the value of the tie itself; while for new work the cost of laying a tie is only 20 cents, making a difference of 80 cents.

"For the purpose of comparison let us take a mile of double track. The bill of timber therefor is as follows:

Ties....	9 052:	6 ins.	x	8 ins.	x	8 ft.....	289 664 ft.
Guards.	920:	6 "	x	8 "	x	24 ".....	88 320 "
Guards.	920:	8 "	x	8 "	x	24 ".....	117 760 "
Planks..	5:	2 "	x	8 "	x	5 280 ".....	35 200 "
Joists ..	1 508:	4 "	x	8 "	x	8 ".....	32 171 "
							563 115 ft.
							Say 564 M.

"In order to be absolutely on the side of safety, let us assume the life of the vulcanized timber to be only fifteen years, or just twice that of the untreated timber, and that the excess of cost of replacing ties during traffic over that when there is no traffic is 60 cents instead of 80 cents per tie. The rate of compound interest assumed is 5 per cent. At the end of fifteen years, then, according to these assumptions, the floor in either case would have to be renewed, and the total costs for the fifteen years would be as follows:

For Vulcanized Timber.

564 M at $38.....	$21 432 00
Compound interest on $21 432 for 15 years..	23 125 13
Total.....	$44 557 13

FOR UNTREATED TIMBER.

564 M at $24	$13 536 00
564 M at $24	13 536 00
9 052 ties at 60 cents	5 431 20
Compound interest on $13 536 for 15 years	14 605 30
Compound interest on $18 967 for 7½ years	8 383 50
Total	$55 492 00

"According to these figures the untreated timber is about 25% more expensive than the vulcanized timber, even upon assumptions that are manifestly unfavorable to the latter."

XIII.—BEST AND CHEAPEST MATERIAL FOR PEDESTAL CAPS.

Estimates of cost were made on several types of pedestal caps, including castings like those used on the Metropolitan Elevated, Kettle River sandstone blocks and granitoid; and the last was adopted because it was considered both the cheapest and best. Experience with the finished pedestals has given the company's engineers no reason to regret their decision concerning this matter. The granitoid covering for the concrete of the pedestals is 6 ins. thick, and is composed of one part of Portland cement, two parts of fine granite screenings and four parts crushed granite, no piece being too large to pass through a ring ¾ in. in diameter, the top surface being made extremely smooth, to exact elevation, and perfectly level.

XIV.—BEARING CAPACITY OF CHICAGO SOIL.

Mr. Rowe made a number of experiments on the bearing capacity of Chicago soil, using an apparatus designed by the author, by which a load of pig iron was applied centrally to a square block of timber. As Mr. Rowe has promised to treat this subject in his discussion, no further details will be given here, except to state that the safe load in some places ran as low as 1 ton per square foot.

XV.—BEST STYLE OF ANCHORAGE FOR COLUMNS.

Where longitudinal sway bracing is employed, two anchor bolts per pedestal were used; but, where reliance was placed on the transverse strength of the column to resist the bending effects of longitudinal and transverse thrusts, four anchor bolts per pedestal were employed. All the anchor bolts of each pedestal were passed through a single anchor casting or spider embedded in the concrete and set

very carefully to exact line and level. The details of the foundation are shown in Fig. 5. The upper ends of the anchor bolts are enclosed loosely with a curved steel plate, long enough to contain an ample number of rivets for attaching to the column, and having a square and smooth top to receive a heavy steel washer plate. As there are enough rivets connecting the curved plate to take care of both the direct and the secondary or induced stresses due to eccentricity, this entire pedestal detail is such as to make the column and the pedestal absolutely continuous, so that they act as a unit in resisting overturning; hence all calculations of strength of parts were made upon the assumption that the foot of the column is fixed.

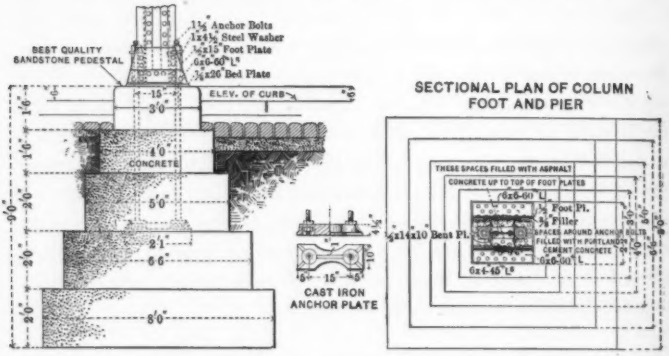

FIG. 5.

A detail similar to this was employed by the author in 1891 when designing the columns and pedestals of the Sioux City train-shed; and, as far as he knows, this was the first time that a column-foot detail involving a truly fixed end for the column was ever used.

The ordinary method of running the anchor bolts through the horizontal foot-plate of the column near its edges or corners does not make a fixed-end column—far from it, as a few simple calculations will show.

XVI.—PLATE GIRDERS *versus* OPEN-WEBBED GIRDERS.

In designing these elevated railroads for Chicago, many estimates for both plate and open-webbed girders have been made, which

demonstrate that there is practically no difference in the weight when both girders are properly designed. As the open-webbed girders cost a trifle more per pound to manufacture, there is no economy in their use; nevertheless they were adopted for all structures running longitudinally in the streets in order to comply with certain city ordinances.

The observance of these ordinances was sometimes carried to extremes, producing ridiculous combinations of solid and open web in the same girder, and an evident waste of material and labor. For this the engineers are not to blame, as it was not they who framed the ordinances.

XVII.—Crimping of Web-Stiffening Angles *versus* the Use of Filling Plates.

An investigation of this question was made by writing to a number of the leading bridge companies, and propounding to them this query: "If you had a lump sum contract for building a bridge would you find it more economical to use crimped angles for web stiffeners, or to adopt plain angles with fillers beneath them?" Some replies favored crimping and some did not; but the majority, including most of the larger companies, considered crimping a little the more economical, especially for intermediate stiffeners; consequently on the Chicago work all intermediate stiffeners are crimped, and all end stiffeners have filling plates.

XVIII.—Best Sections for Columns.

Investigation concerning strength, capacity to resist impact, facility of erection, economy of metal, etc., determined that the section for columns located in the street should be two 15-in. rolled channels with the flanges turned inward and a 15-in. rolled I-beam riveted between to act as a central web or diaphragm, the flanges of the channels being held in place by interior stay plates spaced about 3 ft. centers. In most cases the column feet pass below the pavement and are embedded in the concrete, to which, of course, they are bolted, but in some cases they rest on pedestals a little above the level of the sidewalk. The main object in turning the flanges inward is to enable the column better to resist impact from heavily loaded vehicles. Just

above the pavement there is a curved casting filled with concrete and surrounding the column to act as a fender.

This column is a very satisfactory one after it is erected, although it gives some little difficulty in the shops and involves a little more field riveting than usual. One complaint made was that the top and bottom planes of flanges of I-beams are never exactly parallel to each other, so that some straightening was necessitated.

For columns located on private property or on sidewalks where the structure is transverse to the street, four Z-bars and a web plate were adopted as the most satisfactory section. At the top of the column a wide curved web plate and curved angles are used. This design makes a most satisfactory column, which goes through the shops readily, and which is well adapted for quick erection. It is true that it necessitated a special tool for cutting the webs to a circle, but after this was made, the manufacture was easy and comparatively inexpensive. The Union Bridge Company, of Athens, Pa., and the Elmira Bridge Company, of Elmira, N. Y., together took the contract for the metalwork of the entire Northwestern Elevated and the Fifth Avenue side of the Union Loop. The Lake Street side of the Loop was built by the Phœnix Bridge Company of Phœnixville, Pa., and the other two sides are being built by the Pencoyd Iron Works of Pencoyd, Pa.

Figs. 6 and 7 illustrate features of the column construction, the latter figure also showing the details of an expansion joint.

XIX.—Best Style of Expansion Joint.

The designing of a perfectly satisfactory expansion joint is no simple problem; consequently, it demanded considerable study, the result of which was the adoption of the pocket shown in Figs. 8 and 9 to receive the loose end of a longitudinal girder. The most important feature of this design is that the center of pressure from the longitudinal girder is distant from the cross-girder about half the length of the pocket, which reduces the moment due to eccentricity upon the group of rivets connecting the pocket to the cross-girder, and prevents the bearing of the longitudinal girder from coming on an edge of metal as would be the case were not the center of pressure thrown towards the cross-girder by the small base plate. Again, the number of rivets connecting the pocket to the cross-girder is ample for both the direct

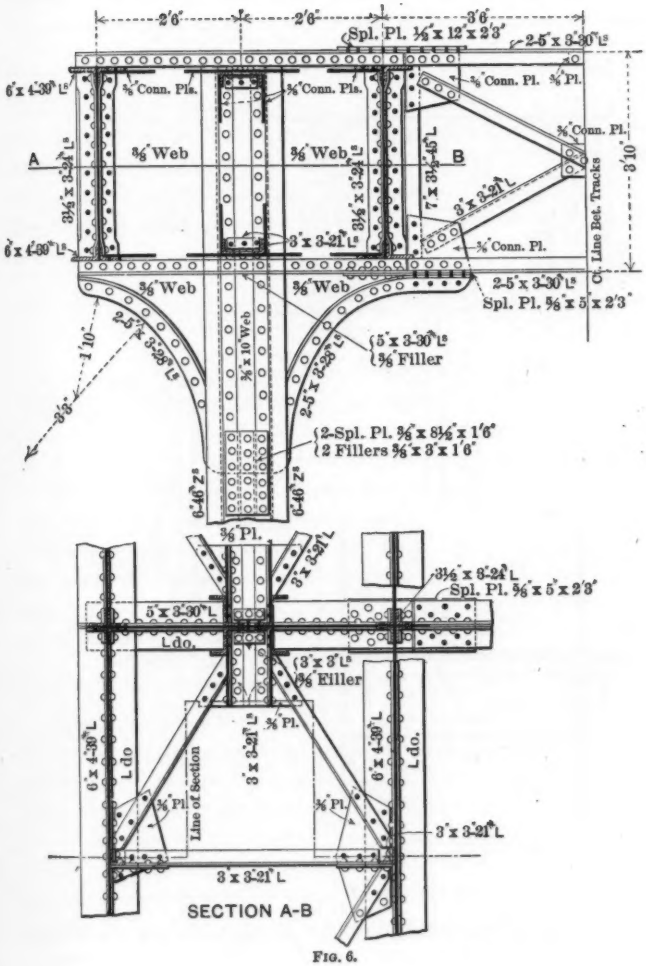
2'6"
2'6"
3'6"
Spl. Pl. ½" x 12" x 2'3"
2-5" x 3-30" L's
6" x 4-30" L's
⅝" Conn. Pls.
⅝" Conn. Pls.
⅝" Conn. Pl.
⅝" Pl.
⅜" Conn. Pl.
A
⅝" Web
⅝" Web
B
3½" x 3-24" L's
3½" x 3-24" L's
7" x 3½" x 45" L
3" x 3-21" L
3'10"
Ct. Line Bet. Tracks
⅜" Conn. Pl.
6" x 4-30" L's
⅝" Web
⅝" Web
2-5" x 3-30" L's
Spl. Pl. ⅝" x 5" x 2'3"
1'10"
2-5" x 3-28" L's
3'3"
3⅛" x 10" Web
5" x 3-30" L's
⅜" Filler
2-5" x 2-28" L's
2-Spl. Pl. ⅜" x 8½" x 1'6"
2 Fillers ⅜" x 3" x 1'6"
6-46" Z's
6-46" Z's
⅜" Pl.
3" x 3-21" L
3½" x 3-24" L
Spl. Pl. ⅝" x 5" x 2'3"
5" x 3-30" L's
L do.
(3" x 3" L's
⅜" Filler
⅜" Pl.
3" x 3-21" L's
6" x 4-30" L's
L do.
L do.
⅜" Pl.
Line of Section
⅜" Pl.
3" x 3-21" L
3" x 3-21" L
SECTION A-B

FIG. 6.

shear and the secondary stresses due to the moment caused by the eccentric bearing. The longitudinal girder fits tightly laterally in the pocket, and its top is held between angle clips riveted to the cross-girder. Thus the expansion ends of the longitudinal girders are held

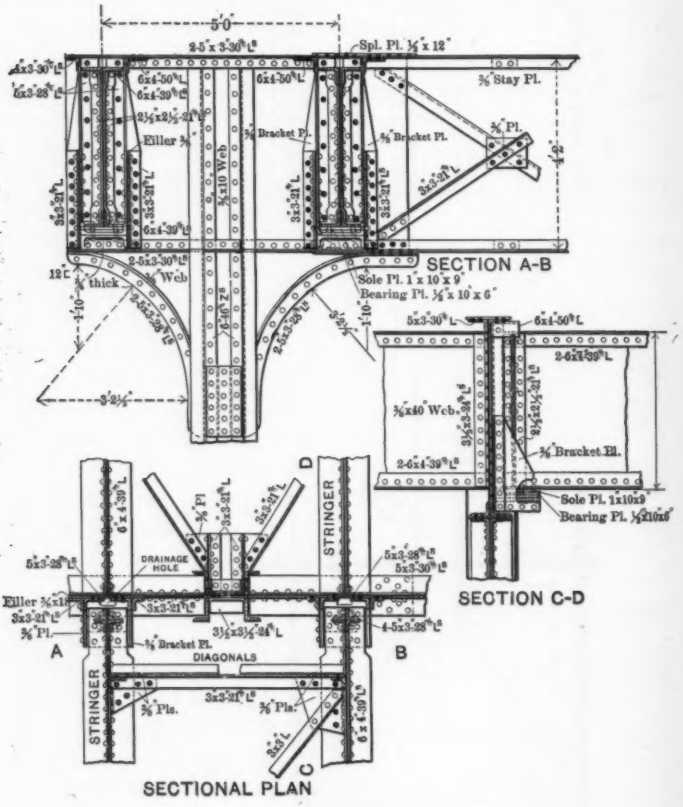

FIG. 7.

laterally to the cross-girders just about as rigidly as are the riveted fixed ends.

The detailing of the entire expansion end is so arranged that all parts of the metalwork are accessible to the brush for painting, al-

though extra care will have to be used by the painter on this portion of the structure, in order to make sure that no portion of the surface is unprotected.

XX.—Style of Bracing on Curves.

The extra bracing on curves is composed of two lower lateral systems, each pertaining to two tracks, and consisting of a double system of cancellation, the diagonals being formed of two 4 x 3-in. angles riveted together and to the lower flanges of the longitudinal girders where they cross the same. The columns on curves are made larger and stronger than those on tangents, in order to resist properly the centrifugal loads.

XXI.—Proper Limit of Length of Structure between Expansion Joints.

This question involves the effects of changes of temperature, more especially in producing bending on the columns. The latter were figured for deflection with due regard to the fixedness of their ends, which increases the extreme fiber stresses due to changes of temperature. The investigation showed that 150 ft. should be the ordinary limiting distance between expansion points. On almost the entire lines of the Northwestern and Loop, this limit was observed; but in two or three cases, owing to peculiar local conditions, it had to be exceeded. In these cases, however, the columns most affected were strengthened.

XXII.—Track-Bolt Nuts Above *versus* Track-Bolt Nuts Below.

Each method has both good and bad features. With nuts below, the hole through the wood can readily be protected from the entrance of water, but the nuts may work off the bolts without notice being taken of the fact by the track-walker. With nuts above, any loosening of the bolts would be seen at once, but a water-tight joint is hard to make. The latter arrangement, after much discussion, was adopted, and cup-shaped washers let into the wood were employed. A liberal use of paint in these cups will probably seal them against percolation of water, but their insertion in the wood seems like an invitation for rot. An important advantage in using these cups is that there are no projecting nuts above the wood to trip anyone walking over the track.

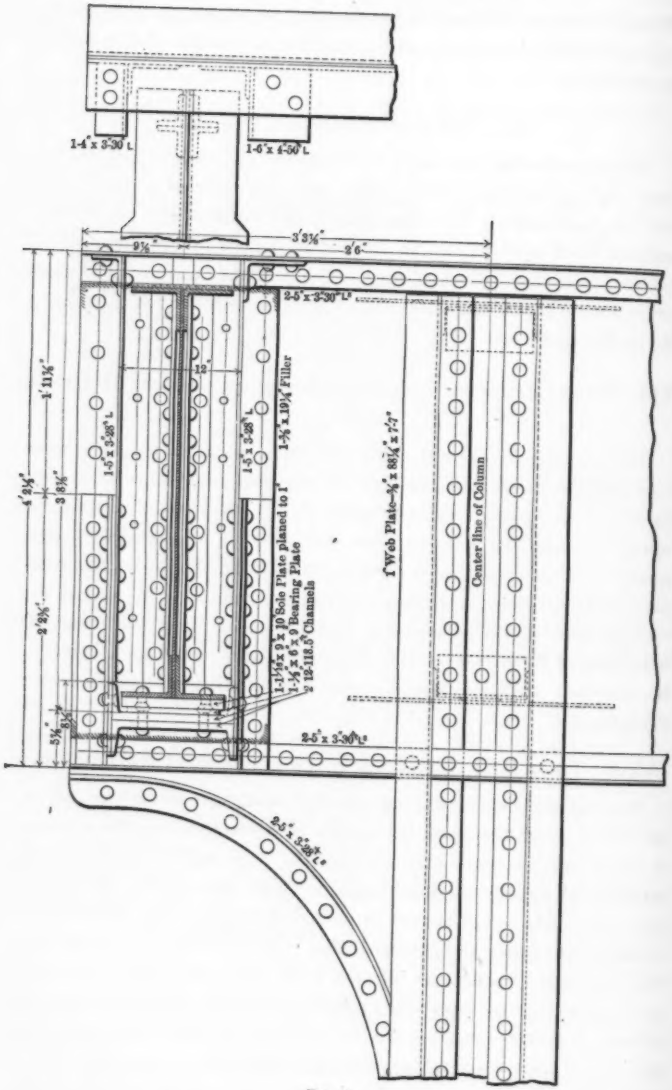
1-4" x 3-30 L
1-6" x 4-50 L
3'3½"
9½"
2'6"
2-5" x 3-30" L
1'-11½"
4'2½"
3'8½"
2'8½"
5¾"
6½"
1-5" x 3-28" L
12"
1-5" x 3-28" L
1-⅝" x 19¼" Filler
1'Web Plate—⅜" x 86¼" x 1'-7"
Center line of Column
1-1½" x 9" x 10' Sole Plate planed to 1'
1-⅛" x 8" x 9' Bearing Plate
2 12"-110.5# Channels
2-5" x 3'-30" L
2-5" x 3'-30" L

FIG. 8.

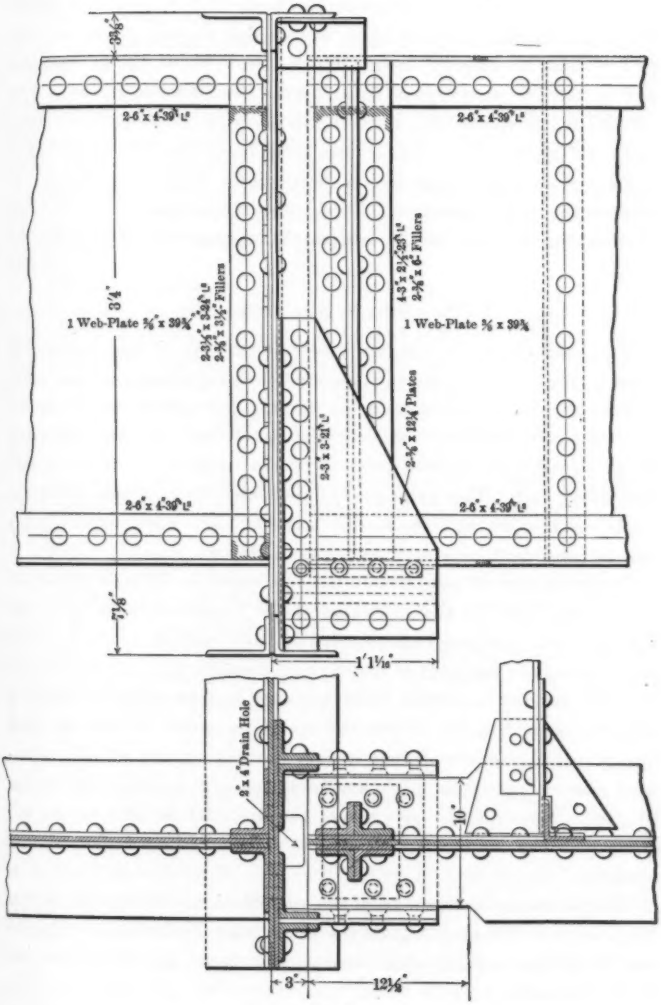
3½"
2-6" x 4-39" L's
2-6" x 4-39" L's
3'4"
1 Web-Plate ⅝" x 39¾"
2-3½" x 3½" L's
2-⅝" x 3½" Fillers
4-3" x 2½" 25" L's
2-⅝" x 6" Fillers
1 Web-Plate ⅝ x 39¾
2-⅝" x 18¾" Plates
2-3" x 3" L's
2-6" x 4-39" L's
2-6" x 4-39" L's
7⅛"
1'1⅛"
8" x 4" Drain Hole
10"
3"
12½"

FIG. 9.

XXIII.—Superelevation on Curves.

It was decided not to attempt to obtain this by elevating or depressing the longitudinal girders, or by using wooden shims on outer girders, but to employ wedge-shaped ties. Three bevels only are used on the line, viz., 1, 2 and 3 ins. in 5 ft. Such bevels, it is true, will not afford the theoretical superelevation required for the maximum speed on sharp curves; but it was considered that this maximum speed could not be maintained on sharp curves, hence the compromise between theory and practice. Experience in operation alone will tell whether the decision of the company's engineers in this matter is correct.

XXIV.—Best Styles of Stations.

For stations on the company's private property it was decided to adopt a single brick house to accommodate the entering passengers for all four tracks, the exit passengers leaving the platforms by special exit stairways leading to or near the street, each of said stairways being provided at its foot with a turnstile prohibiting entrance but permitting exit. This arrangement dispenses with several platform employees and prevents the station house and stairways from obstruction by passengers moving in opposite directions.

At first it was intended to run the exit stairways at right angles to the line and land on the sidewalks of the cross-streets, as shown in Fig. 10, but it was found afterwards that this method would in some cases involve the payment of unduly high damages to property-owners, so it was decided to confine these stairways entirely to the company's property, as in Fig. 11. From the operating point of view the first design is the better one in that it does not cut up the already somewhat narrow platforms with apertures for exit, as does the design adopted. However, the pressure of the financial department was too strong for the engineers; consequently, the proposed change was adopted.

The following extracts from the specifications for stations on the Northwestern Elevated, together with occasional reference to Figs. 10 and 11, will give a fairly clear idea of what these stations will be like when completed.

"There are two slightly different styles of stations on the line, viz.: 'Interior Track Stations' and 'Exterior Track Stations,' the

former being placed at intervals of about one mile, and the latter at intervals of about a quarter of a mile.

"The essential points of difference in the two styles of stations are in the platforms and in the vestibule and stairways leading thereto.

"In the Exterior Track Stations the platforms are outside of the tracks, while in the Interior Track Stations they are between the exterior tracks and those adjacent thereto, the exterior tracks being spread so as to pass around the platforms.

"There will be but one house to each station, passengers entering the same from the street, but not passing through it when leaving the line, as special exit stairways leading to the street are provided.

"The houses are to be built as follows: The basement walls are to be composed of rubble, resting on dimension stone footings; the main walls are to be of common brick, faced with pressed brick and terra cotta trimmings; the roof is to be a composition gravel roof; the floors are to be of white oak, resting on common yellow pine flooring over yellow pine joists; and the finish is to be of antique oak. The houses are to be lighted by both electricity and gas, and are to be heated by hot water.

"The ticket office is located to one side of the rear vestibule, which latter leads to the entrance stairways, which in turn lead to the platforms.

"These platforms are to be constructed of transverse and longitudinal timbers with a two-inch (2") vertical-grain yellow pine flooring on top. They are to be sheltered by canopies of corrugated iron supported by steel frame construction.

"Around all stairway openings, along the outside of exterior platforms, and at ends of all platforms are to be gas-pipe hand-railings paneled with grillework screens."

XXV.—Best Method of Heating Stations.

After considerable deliberation and discussion it was decided to heat all stations with hot water. This is undoubtedly the most satisfactory method for houses on the ground; but for the Loop stations and those of the Northwestern which are supported by the metalwork, the author would have preferred heating by gas so as to avoid the carrying to and fro of coal and ashes, with the unavoidable accompanying dirt and trouble. The use of gas, though, would have been more expensive than that of coal.

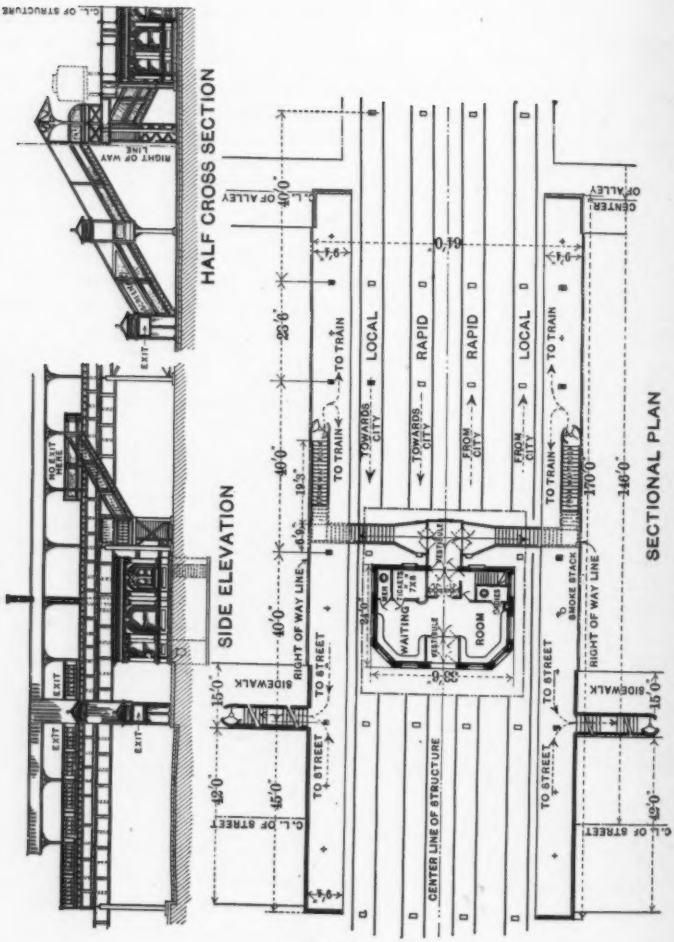
HALF CROSS SECTION
SIDE ELEVATION
SECTIONAL PLAN
C.L. OF STRUCTURE
RIGHT OF WAY LINE
EXIT
NO EXIT HERE
C.L. OF ALLEY
40'0"
23'0"
TO TRAIN
LOCAL
RAPID
TOWARDS CITY
FROM CITY
0.19
7.6
40'0"
19'3"
16'0"
RIGHT OF WAY LINE
SIDEWALK
TO STREET
15'0"
45'0"
C.L. OF STREET
24'0"
WAITING ROOM
TICKET BOOTH 7X8
VESTIBULE
MEN 9X23
WOMEN 9X23
0.05
CENTER LINE OF STRUCTURE
170'0"
146'0"
BROKE STACK
CENTER OF ALLEY

Fig. 10.

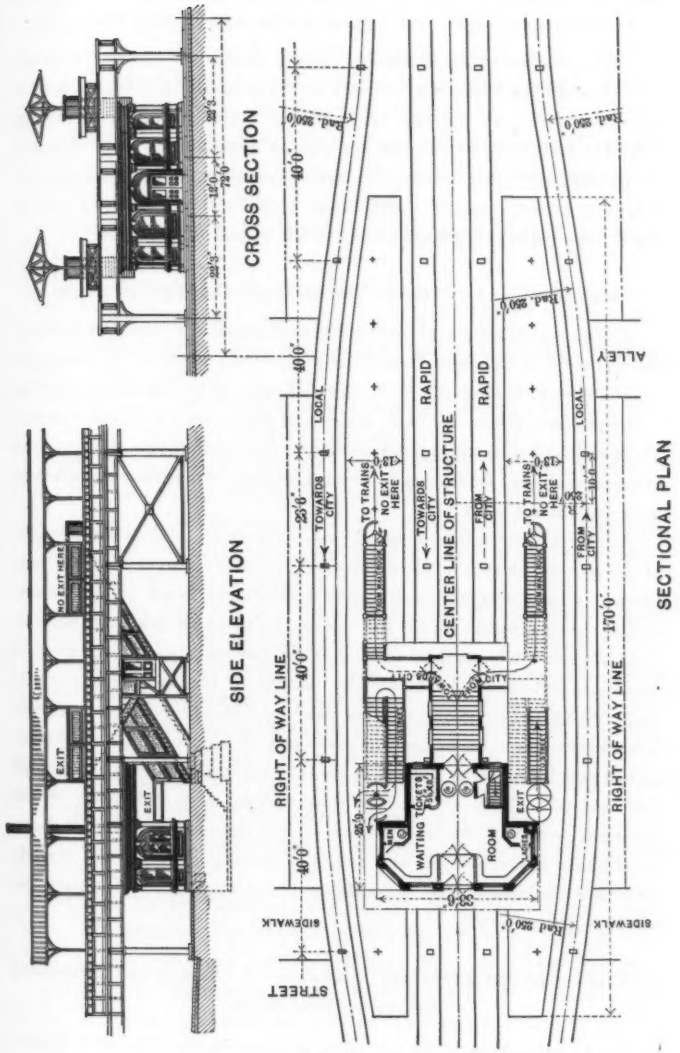
CROSS SECTION
SIDE ELEVATION
SECTIONAL PLAN
RIGHT OF WAY LINE
CENTER LINE OF STRUCTURE
LOCAL
RAPID
RAPID
LOCAL
ALLEY
STREET
SIDEWALK
SIDEWALK
TOWARDS CITY
FROM CITY
TO TRAINS
NO EXIT HERE
WAITING ROOM
EXIT
NO EXIT HERE
EXIT
170'0"
40'0"
22'0"

Fig. 11.

XXVI.—Relative Costs of Double-Track Structure with Columns in the Street and with Columns Just Inside of Curb Lines.

This question was investigated so as to determine whether in certain cases it would be worth while to strive for permission to put the columns in the street. As will be seen in the table given under Section XXVIII, the cost of structure per mile of double track was estimated to be $267 760 with columns inside of curbs, and $240 537 for columns in street, making a difference of $27 223 per mile of double track, or a relative difference of between 11 and 12 per cent.

XXVII.—Pressed-Thread Bolts *versus* Cut-Thread Bolts.

As the manufacture of pressed-thread bolts is a patented process, the author first obtained from the patentees a guaranteed pound price for their bolts delivered f. o. b. cars Chicago, at the same time getting corresponding prices for both upset and plain bolts with cut threads. He then had his metal inspectors test to destruction several specimens of pressed-thread bolts so as to determine their strength in comparison with cut-thread bolts.

As the difference in the pound prices was small, and as the strength of the pressed-thread bolts is fully 50% greater than that of the cut-thread bolts, the comparison resulted greatly in favor of the former, so they were adopted for all the anchor bolts and track bolts on both lines of road. The author feels that he cannot speak too highly of these pressed-thread bolts, for the results of the tests were surprising. When it is considered that the cold-pressing process reduces the effective diameter of the soft steel rod at the root of the thread, and in fact increases it but little at the edges, it might be imagined that when the bolt is tested to destruction, it would break in the threaded portion. Such, however, is not the case, for all the specimens broke in the body of the rod, and, strange to say, the threads were so little injured that the nuts could be turned readily over the whole length of same.

XXVIII.—Studies Involving a Number of Designs for Different Styles of Structure.

The investigations included under this heading are the most elaborate of all those made. They involved careful designs and estimates

of cost of the following types of structure, all of which are shown in cross-section in Figs. 12 to 24 inclusive.

Design 1. Four-track structure with longitudinal bracing, supported by four Z-bar columns, the cantilevers and columns being made in one piece in the shops.

Design 2. Similar to Design 1, except that the cross-girders are riveted to the columns in the field, and the brackets are omitted.

Design 3. Four-track, two-column structure, with longitudinal bracing.

Design 4. Four-track, four-column structure, without longitudinal bracing.

Design 5. Four-track, two-column structure, without longitudinal bracing.

Design 6. Double-track, two-column structure, with longitudinal bracing, similar to Design 1.

Design 7. Double-track, two-column structure, with longitudinal bracing, similar to Design 2.

Design 8. Double-track, two-column structure, with longitudinal bracing, the columns being spaced 17 ft. centers transversely to the structure.

Design 9. Double-track, two-column structure, without longitudinal bracing, similar in construction to Design 4.

Design 10. Four-track, four-column structure, without longitudinal bracing, the columns being flared out at the top and extending only to the plane of the bottoms of stringers, and the column section being composed of two 15-in. I-beams.

Design 11. Four-track, four-column structure, similar to Design 10, except that channels are used instead of I-beams in the columns.

Design 12. Double-track, two-column structure, without longitudinal bracing, for the alternative route along Fifth Avenue and Franklin Street, the columns being placed on the curbs.

Design 13. Double-track, two-column structure, without longitudinal bracing, also for the alternative route along the streets, the columns in this case being placed in the roadway.

The following is an almost verbatim extract from the author's report, all references to drawings being omitted.

In explaining and discussing each of these designs, the following questions in the order here given will be considered: First, general description; second, strength; third, rigidity; fourth, economy; fifth, æsthetics; sixth, uniformity of construction; seventh, facility of manufacture and erection.

In making these various calculations there has been assumed a typical block 292 ft. long, simply for purposes of comparison. This block, however, is of about the average length of the blocks through which the line will pass.

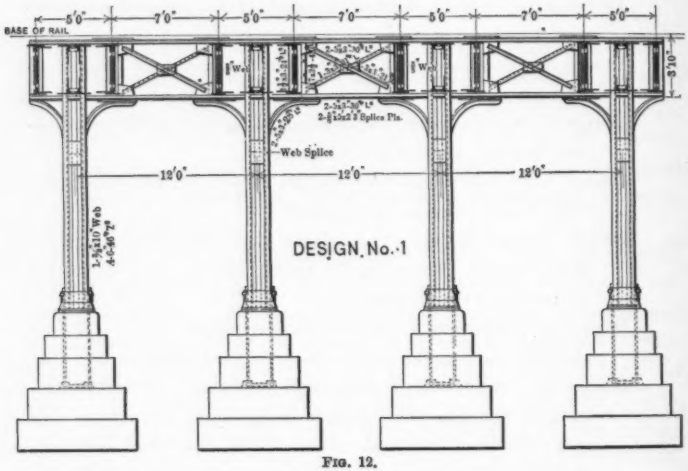

FIG. 12.

Design 1, Fig. 12.

Design 1 is a four-track structure which is supported by four Z-bar columns.

General Description.—Each track is carried by a column which is located directly beneath its central line. The stringers are spaced 5 ft. apart, and are, therefore, almost directly beneath the rails. They are carried by short cantilevers, one on each side of the column. The web of these two cantilevers and that of the top of the Z-bar column are all in one piece, this web being carried through the top of the column. The top flange of the cantilevers is also continuous over the top of the column, and its web is carried far enough down the column to form a good bracket on each side.

The spans are all to be 40 ft. in length, excepting those over the street, which are 45 ft., and those having longitudinal bracing, which are 23 ft. 6 ins. There will be two such braced spans to each 292-ft. block, and a correspondingly greater number for blocks of greater length. This longitudinal bracing is designed to take up the entire horizontal thrust due to braked trains or to traction, the intermediate columns being designed to carry only the direct load and transverse thrust from wind load.

The stringers or longitudinal girders are plate girders, riveted up solidly to the cantilever brackets, except at the expansion ends. The expansion joints are spaced about 150 ft. apart, and will be similar in design to those used on the Wabash Avenue Extension of the Lake Street Elevated Railroad. The longitudinal thrust due to expansion and contraction of the stringers is carried to the column in each bent by short struts, but the longitudinal thrust due to braked trains is carried by the stringers directly to the longitudinal bracing.

On curves, where permissible, a system of vertical sway bracing will be used, and, where it cannot be employed, the columns will be made strong enough to transmit the transverse thrust to the pedestals.

These pedestals are to be made of concrete, covered with granitoid.

Strength.—Every portion of this structure has been made amply strong to carry the greatest stresses and loads which can come upon it. It would be difficult to make stronger or more efficient columns and cantilevers than the ones used throughout this design; for these columns, cantilevers and brackets are made in one piece in the shops, and there is not a weak point in them.

The bracing towers, if they may be so termed, are well braced, both longitudinally and transversely in vertical planes, and horizontally at the top, and take care most effectively of the total longitudinal thrust.

Rigidity.—The stringers are thoroughly braced together so as to prevent as much as possible all transverse vibration, and this bracing, together with the longitudinal sway bracing in the towers, prevents any undue longitudinal vibration. As the columns are placed directly beneath the centers of the tracks, there is no possibility of unequal deflection in the transverse girders and cantilevers, such as might occur if the columns were not so placed. All columns are anchored to the pedestals by long anchor bolts which extend well into the concrete and make the column and pedestal act as one piece. Upon the whole this design is so constructed as to make it as rigid a structure as can be obtained.

Economy.—While this structure has been made thoroughly first class in every respect, no material has been wasted in so doing. The spans have been made of the most economical lengths; the spacing of columns transversely to the structure, the sections of columns used, the style of cantilever and the stringer bracing are all examples of true

economy of design, but probably the feature that saves more metal than any other is the use of longitudinal sway bracing in the towers, as will be seen by comparing the weights of Designs 4, 10 and 11, and the one now under consideration. This comparison shows that from 140 lbs. to 165 lbs. of metal per lineal foot of structure have been saved in Design 1, or from $8 000 to $11 000 per mile of same, and at the same time a more rigid and stronger structure has been evolved than that illustrated in any of the other four-track designs.

From an economic point of view, only one of the designs, viz., Design 3, offers any advantage over Design 1, but there are other considerations which offset this apparent economy in Design 3.

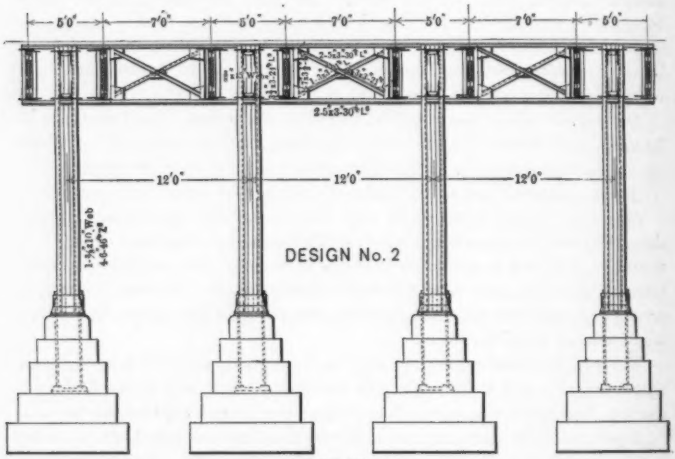

FIG. 13.

Æsthetics.—This structure is light and airy, and upon the whole presents a very neat appearance; more so, perhaps, than any one of the other designs.

Uniformity of Construction.—The style of construction will be the same throughout, with only very slight alterations at stations and on curves, the double-track structure included. This will not be true of several of the other designs.

Facility of Manufacture and Erection.—The style of column used makes it practicable to do nearly all of the riveting in the shops, the cantilevers and brackets, as before stated, forming a part of the column. As the cross-girders have no direct load to carry whatsoever, they are made very light, and are to be connected to the cantilevers in the field, the rivets necessary to make this connection, to-

gether with those connecting the stringers to cantilevers and sway bracing, being the only field rivets required.

The work is all plain and straight, excepting the curved brackets. All parts are made of as few pieces as possible, and there are no large or unwieldly members to handle.

This design will be easier to manufacture and erect than any one of the other designs now under consideration.

Design 2, Fig. 13.

This is similar to Design 1.

Strength.—As far as the strength of the various parts of the structure is concerned, this design is almost the same as Design 1. The same sections are used in the stringers, columns, cross-girders and transverse and longitudinal bracing.

Rigidity.—This design will not be quite so rigid as Design 1, as there are no brackets beneath the cross-girders, and the method of connecting the cantilevers and cross-girders to the columns is not so good, for in Design 1 the cantilevers and columns are all made in one piece; otherwise, the two designs are identical.

Economy.—The cost of Design 2 is the same as that of Design 1, viz., $65 10 per lineal foot (average), including curves.

Æsthetics.—Owing to the omission of the brackets, this design does not appear so well as does Design 1.

Uniformity of Construction.—What was said of Design 1 applies to Design 2 as well.

Facility of Manufacture and Erection.—In this case the cantilevers and cross-girders are riveted up to the columns in the field; this necessitates driving more rivets in the field than in case of Design 1, but all the work is plain and straight, and will be easy to manufacture and erect. Taking it as a whole, this design is not quite so satisfactory as Design 1, and it costs quite as much money.

Design 3, Fig. 14.

Strength.—Design 3, as well as all the others, has been made good and strong in all its details.

Rigidity.—This design is a two-column, four-track structure, with the two outer tracks cantilevered out beyond the columns, which are spaced 24 ft. centers in planes transverse to the structure. While the structure has been designed to be as rigid as is possible with this style of construction, the unequal distribution of load and the lengths of cantilever and girder necessary do not insure the rigidity which is obtained in Designs 1 and 2.

Laterally, the structure is well braced; and, longitudinally, the braced towers are used, as in the preceding designs.

Economy.—This design is a trifle cheaper than Designs 1 and 2, on account of the saving in pedestals, the metalwork costing considerably more, though, than in those designs.

Cost of Design 1.....	$65 10
Cost of Design 3.....	64 60
Difference.....	$0 50, or $2 640 per mile.

Æsthetics.—This structure is by no means a good-looking one.

Uniformity of Construction.—In this design in changing from four-track to double-track structure, it will be necessary to change en-

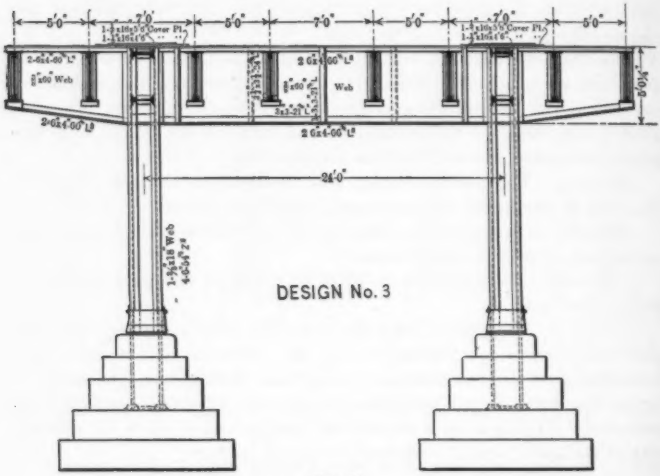

FIG. 14.

tirely the style of construction, which is not the case in Designs 1 and 2.

Facility of Manufacture and Erection.—In this design all cross-girders and cantilevers must be riveted to the columns in the field, and, owing to the great depth of these girders, this will make this structure difficult to erect. The girders are all heavy and unwieldy, much more so than in the four-column structures. The work in the shops will be easy.

While the structure is, perhaps, apparently a little more economical than Design 1, it has the disadvantages of being unsightly, of lacking rigidity, and of being difficult to erect.

Design 4, Fig. 15.

General Description.—Design 4 differs from Designs 1, 2 and 3 in the fact that no longitudinal sway bracing is used, but each column is made strong enough to take up the longitudinal thrust coming upon it. The spans through the blocks are about 50 ft. long.

This is a four-column, four-track structure, each column being fixed at top and bottom in planes transverse and parallel to the structure. The columns are anchored to the pedestals by four anchor bolts instead of two, as in the preceding designs.

Rigidity.—As the only longitudinal rigidity obtained is solely through the efficiency of the columns to resist bending, it is evident that

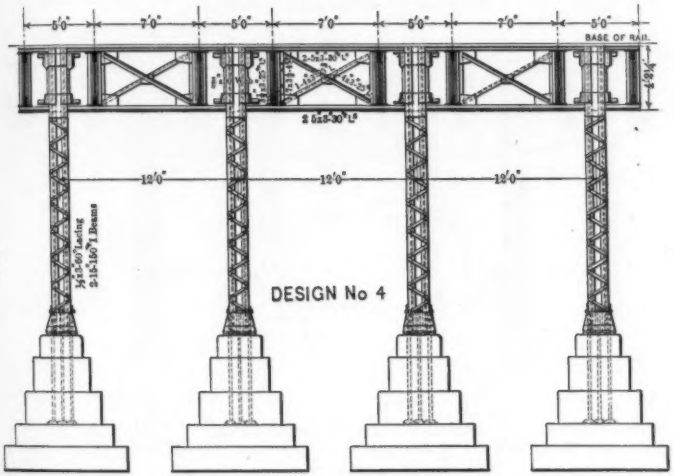

FIG. 15.

this design will not be as rigid in this direction as Designs 1, 2 and 3. There are no brackets transverse to the structure; hence, it will not be as rigid laterally as Design 1. The stringers are well braced together and to the columns. On curves, transverse sway bracing will be used where permissible, and where it is not, the columns will be strengthened, so as to take care of the centrifugal load.

Economy.—This is the most expensive design yet considered, the average cost per lineal foot being $66 65 instead of $65 10 for Design 1.

Æsthetics.—Design 4 has nothing to commend it from an æsthetic point of view.

Uniformity of Construction—Like Designs 1 and 2, this design has the advantage of being adapted to both double and four-track structures.

Facility of Manufacture and Erection.—This design would be easier to erect than Design 3, but not so easy as Design 1. The shopwork would be somewhat difficult.

Design 5, Fig. 16.

General Description.—This is a two-column, four-track structure, and, like Design 4, has no longitudinal sway bracing. The columns are built up of plates and angles, and are designed to carry the longitudinal and transverse thrusts due to braked trains and to wind load. The spans are of the same lengths as in Design 4.

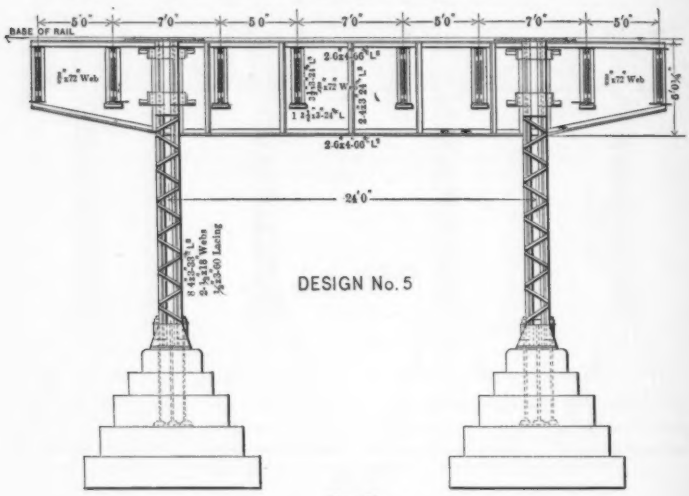

FIG. 16.

Rigidity.—The remarks made under this head for Design 3 apply to Design 5 as well; but, in addition to the defects of the former, Design 5 lacks the longitudinal sway bracing, and so will not be as rigid as Design 3.

Economy.—Design 5 is the most expensive design on the list, the cost per lineal foot being $67 60.

Æsthetics.—Like Design 4 it has no commendable features in this respect.

Uniformity of Construction.—Like Design 3 this style of structure could only be made to apply to the four-track railway.

Facility of Manufacture and Erection.—The style of columns used would be somewhat difficult to manufacture, and the great amount of field riveting would make the erection expensive.

From the foregoing facts it will be seen that this design has several disadvantages and is also very expensive, although it has some good features.

Design 6, Fig. 17.

General Description.—Design 6 is similar to Design 1, but is a double-track structure. The remarks under Design 1 in relation to rigidity, æsthetics, and facility of manufacture and erection apply to this case also.

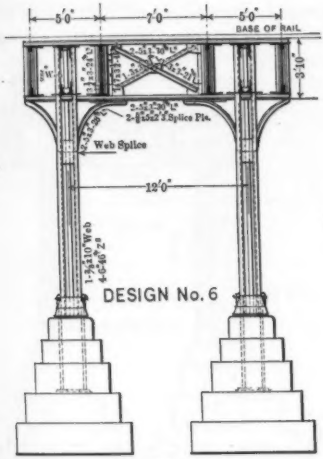

FIG. 17.

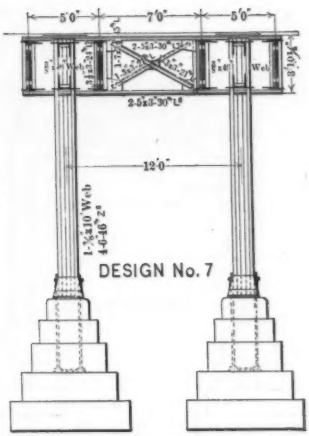

FIG. 18.

Economy.—The cost per lineal foot is $32 65.

Uniformity of Construction.—By using this design for double-track structure and Design 1 for the four-track structure, the design will be the same for columns, stringers, bracing towers, expansion ends, etc., throughout the whole line. If at any time it be considered necessary to convert double-track structure into a four-track structure, it can be done by simply adding a column at each side of the double-track structure, and putting in the additional stringers, cross-girders, and sway bracing.

Design 7, Fig. 18.

Design 7 bears the same relation to Design 2 that Design 6 bears to Design 1. The cost per lineal foot will be $32 65.

Design 8, Fig. 19.

General Description—In this design, which is for double track, the columns are made of four Z-bars, as in Designs 1, 2, 3 and 6, but instead of the columns being directly beneath the center of the tracks, they are placed beneath the outer stringers, thus making the spacing 17 ft. centers, transverse to the structure.

Strength.—The end webs in the cross-girders extend through the columns, forming the webs of the latter at the top, and pass down far enough to form good brackets, thus making the column, end of cross-girder, and brackets all in one piece, which is riveted up solidly in the shop. This makes a very strong connection.

Longitudinal bracing towers are used as in Designs 1, 2, 3, 6 and 7.

Rigidity.—This design is thoroughly braced in all directions, and will be very rigid; but as the columns are attached to the outer string-

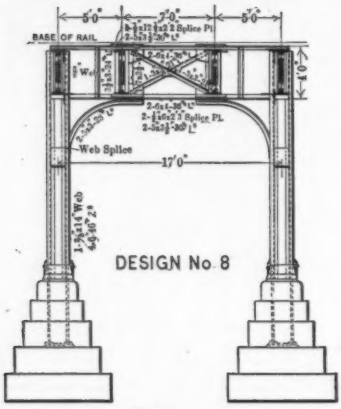

Fig. 19.

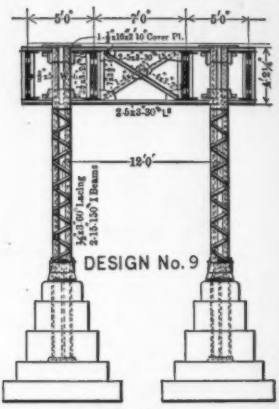

Fig. 20.

ers, and as the inner stringers are supported by the cross-girders, it is probable that there will be some unequal deflection in the stringers; otherwise this design will be as rigid as Design 6.

Economy.—This is the cheapest design on the list for a double-track structure, the average cost per lineal foot being $32 30, while Designs 6 and 7 each cost $32 65. This shows a saving of 35 cents per lineal foot, or $1 850 (nearly) per mile of double track.

Æsthetics.—The cross-section of this design is probably the most æsthetic of any of the designs, and the side elevation at street crossings can be improved by putting in longitudinal brackets beneath the outer stringers.

Uniformity of Construction.—This design necessitates considerable change in the style of construction from that used in the four-track

structure, and it would be difficult ever to convert the double-track structure into a four-track structure in case it should be considered advisable to do so at some future time.

Facility of Manufacture and Erection.—The style of columns and cross-girders used dispenses with nearly all of the field riveting, and will make this a very easy structure to erect. In the shop the work will also be very easy. The lateral system on curves and the stringer bracing used throughout the structure will be easier to connect to the columns and stringers in this design than in any of the other double-track structures now under consideration.

With the exception of the lack of uniformity in construction this design probably offers more advantages than any other for the double-track structure.

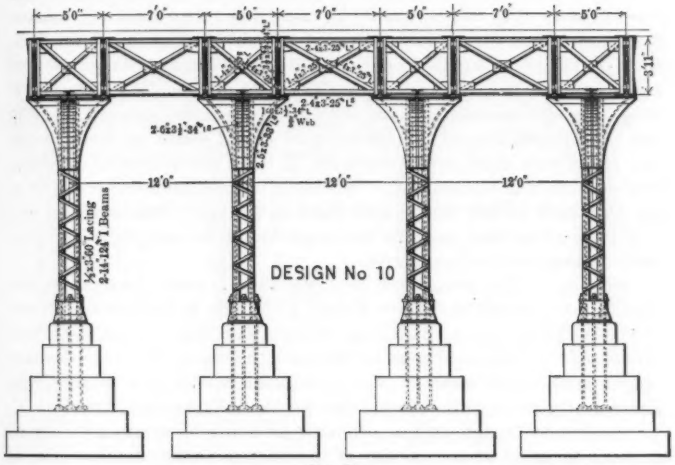

FIG. 21.

Design 9, Fig. 20.

Design 9 is a double-track structure similar in construction to Design 4, and the remarks made under the latter in relation to strength, rigidity, economy, æsthetics, uniformity of construction and facility of manufacture and erection apply to this case also. The cost per lineal foot is $33 31.

Design 10, Fig. 21.

Design 10 is different from any of the designs yet considered, for in all these the columns are carried up to the tops of the cross-girders, while in this the column is carried up only to the plane of the bottom of the stringers, the top of the column being flared out wide enough to receive the two track stringers, which are spaced 5 ft. centers. No

longitudinal bracing is used, so each column is figured to take up in bending its share of the longitudinal thrust.

The columns are made of two I-beams, well laced from the bottom up to the point where the flaring begins, and from this point to the top a large plate is riveted on each of the transverse faces of the column. This design is somewhat similar to the design used on the Metropolitan Elevated Railway of Chicago.

Strength.—Design 10 has been made amply strong in all of its parts.

Rigidity.—As the columns are placed directly beneath the center line of the tracks as in Designs 1, 2, 4, 6, 7 and 9, there will be but little vibration or deflection so far as the vertical loads are concerned, but, as the columns are not carried up to the tops of the stringers and cross-girders, it is impracticable to make the structure rigid against the longitudinal thrust due to braked trains. Longitudinal brackets have been used to fix the upper ends of the columns; but as each of these brackets has to take hold at the center of a small I-beam 5 ft. long, it is evident that the only rigidity that can be procured in this way is dependent upon the efficiency of this I-beam to resist bending, and a very small deflection in the I-beam will permit of considerable deflection in the column. With this bracket and connection, it is not legitimate to call the column fixed at the top. The stringers are well braced together, and the structure would be very rigid laterally, both on tangents and on curves.

Economy.—This design will cost $67 22 per lineal foot, while Design 1 costs but $65 10; hence, Design 1 costs $2 12 less per lineal foot or about $11 200 less per mile than Design 10. The pedestals are more economical in Design 10 than in Design 1, owing to the greater span length used in the former. The additional cost is due to the great amount of metal required to provide for the longitudinal thrust.

Æsthetics.—Design 10 has probably as much to commend it from an æsthetic point of view as any of the designs under consideration.

Uniformity of Construction.—This design, like Designs 1, 2 and 4, can also be used on the double-track structure without any changes in the columns or cross-girders.

Facility of Manufacture and Erection.—This design is very easy to erect, as there is very little riveting to be done in the field. The stringers rest upon the flaring tops of the columns and require only a few rivets to hold them in place. There would be about the same amount of field riveting to be done in this design as in Design 1. There is considerable curved work in both plates and angles in the details at tops of columns, which details are rather complicated; hence the shopwork will be expensive and unsatisfactory.

From the foregoing facts it is evident that Design 10 offers but few advantages and is also an uneconomical structure.

Design 11, Fig. 22.

Nearly all that has been said in regard to Design 10 applies also to Design 11, the principal difference in the two designs being in the section used for the columns. In Design 11 there are two 15-in. channels strengthened by $3\frac{1}{2}$ x 3-in. 23-lb. angles, and near the top the channels are curved outward, so as to provide bearing for the stringers or longitudinal girders. Experience shows that these curved channels are liable to crack.

The cost of Design 11 is exactly the same as that of Design 10. The same provisions are made for longitudinal thrust, but Design 10 would be easier to manufacture, and would be preferable to Design 11.

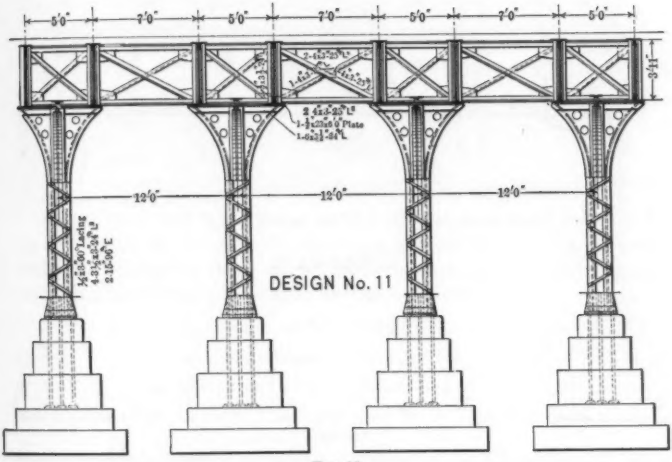

FIG. 22.

Design 12, Fig. 23.

Design 12 is for the alternative route, and is therefore to be placed in the street. Instead of having the columns located in the roadway, as in the Wabash Avenue Extension of the Lake Street Elevated, they will be placed back of the curb lines on the sidewalks, and a heavy cross-girder will span the roadway and support the longitudinal girders, which will be spaced, as in all the other designs, 5 ft. centers, with the two tracks 12 ft. centers. No longitudinal sway bracing can be used, therefore the columns are figured to take up the thrust by bending. The column section will consist of one 15-in. I-beam riveted between two 15-in. channels turned face to face.

Strength.—This design is made very strong, and is thoroughly braced laterally. The columns are each anchored to the pedestals by four anchor bolts which fix their feet, while the tops are fixed by heavy struts extending from the columns to the stringers.

Rigidity.—Owing to the great distance between the columns, transverse to the structure, this design will not be as rigid as Designs 6 and 7, but every precaution has been taken to avoid vibration and deflection. An efficient lateral system has been provided throughout, on tangents as well as on curves, and it will be as rigid a structure as could be expected on this plan.

Economy.—This cannot be called an economical design when compared with the preceding designs for double-track structures, as the

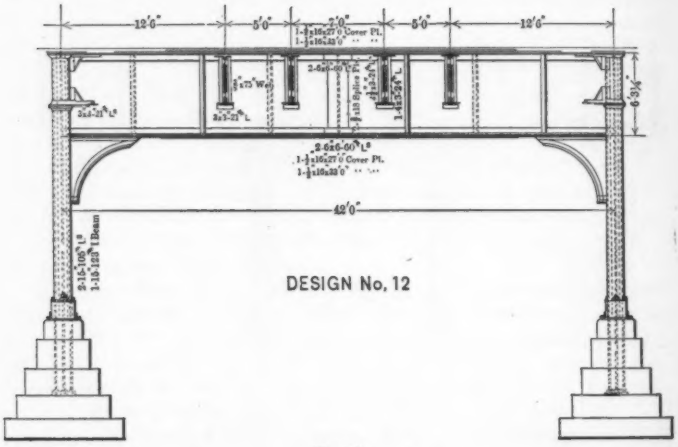

FIG. 23.

total cost per lineal foot amounts to $42, while Design 8 costs but $32 30 per lineal foot. This excessive cost is due to the spacing of the columns and the extra weight of cross-girders occasioned thereby.

Facility of Manufacture and Erection.—This will be a very easy design to manufacture, as it is all straight work; the erection, however, will be much more difficult than that of any of the other double-track structures under consideration, owing to the large number of field rivets to be driven and the great weight of the cross-girders.

Design 13, Fig. 24.

Design 13 is also for the alternative route in case a franchise can be secured permitting the columns to be placed in the roadway. This design is similar to the Wabash Avenue Extension of the Lake

Street Elevated, but plate girders will be used throughout for the stringers. The estimate for Design 13 is based upon the assumption that the columns can be spaced 17 ft. centers on Franklin Street and 22 ft. 8 ins. centers on the remainder of the line.

The average cost of Design 13 would be $36 81 per lineal foot, involving a saving of $5 19 per lineal foot over Design 12, or about $27 400 per mile.

SUMMARY OF COST.

Design.	Weight per lineal foot on tangent.	Weight per lineal foot on curves.	Cost of line per lineal foot.	Cost of line and stations per mile.
1	1 565	1 765	$65 10	$383 728
2	1 565	1 765	65 10	383 728
3	1 590	1 790	64 60	381 088
4	1 700	1 920	66 65	391 912
5	1 750	1 950	67 60	396 928
6	775	875	32 65	210 000
7	775	875	32 65	210 000
8	770	830	32 30	208 544
9	850	960	33 31	213 876
10	1 725	1 950	67 22	394 921
11	1 725	1 950	67 22	394 921
12	1 142	1 182	42 00	267 760
13	916	966	36 81	240 357

In the preceding table there have been assumed four stations to the mile. In the four-track structure one of these is an interior station and the other three are exterior stations, while in the double-track structure all are, of course, exterior stations.

It is in order now to discuss faulty details in existing elevated railroads. This will be done without reference to any road or roads in particular, as the sole object of this discussion is to call attention to important defects in order that they may be avoided in future work.

1.—INSUFFICIENCY OF RIVETS FOR CONNECTING DIAGONALS TO CHORDS OF OPEN-WEBBED, RIVETED GIRDERS.

This defect is more noticeable in old structures than in later ones, especially as the tendency now-a-days is very properly to substitute plate-girder for open-webbed construction. In many of the older elevated roads there is no connecting plate between the diagonal and the chord, but one flange of each of the angles in the diagonal is riveted directly to the vertical legs of the chord angles. This detail involves the use of either two or four rivets to the connection, which is evidently very bad designing, as there should be more rivets used, even if the diagonal stresses do not call for more on purely theoretical

considerations. Where the theoretical number of rivets is very small, additional rivets should be used for two reasons, viz.: First, one or more of the rivets are liable to be loose, and, second, there is nearly always a torsional moment on each group of rivets owing to eccentric connection.

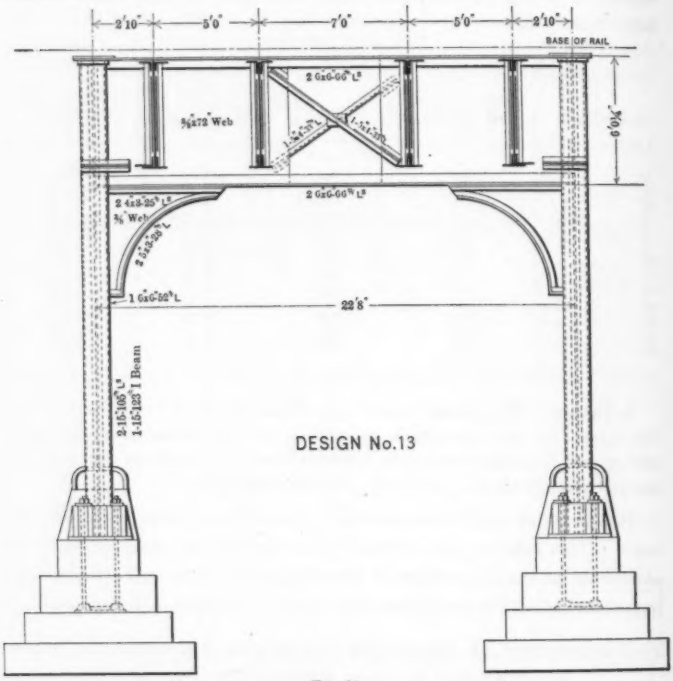

FIG. 24.

2.—FAILURE TO INTERSECT DIAGONALS AND CHORDS OF OPEN-WEBBED GIRDERS ON GRAVITY LINES.

It is very seldom indeed that the designer even attempts to intersect at a single point all of the gravity lines of members assembling at an apex. The failure to do so involves large secondary stresses, especially in the lighter members. By using connecting plates, it is always practicable to obtain a proper intersection; and it is always better to do this than to try to compensate for the eccentricity by the use of extra metal for the main members.

3.—Failure to Connect Web Angles to Chords by Both Legs.

Some standard bridge specifications stipulate that in case only one leg of an angle be connected, that leg only shall be counted as acting, although this stipulation is generally ignored by the designer working under such specifications. It is seldom, indeed, that both legs are connected. In order to settle the question of the necessity for this requirement, the author has had made, in connection with his Northwestern Elevated work, a series of tests to destruction of full-size members of open-webbed girders, attached in the testing machine as nearly as practicable in the same way as they would be attached in the structure. It was intended to settle by these tests the following points: first, effect of connecting by one leg only; second, effect of eccentric connection; and, third, the ultimate strength of star struts with fixed ends, each of these struts being formed of two angles. As these tests are not yet finished, their results cannot be given here. The principal deduction to be made from the tests thus far completed is that an equal-legged angle riveted by one leg only will develop about 75% of the strength of the entire net section, while a $6 \times 3\frac{1}{2}$-in. angle riveted through the longer leg will develop about 90 per cent. It is therefore more economical for short diagonals to use unequal-legged angles connected by the longer leg than to employ supplementary angles to try to develop the full strength of the piece. In fact, the experiments made up to date indicate that these supplementary angles will not strengthen the diagonal essentially. However, further experiments may show the contrary.

4.—Failure to Proportion Top Chords of Open-Webbed Longitudinal Girders to Resist Bending from Wheel Loads in Addition to Their Direct Compressive Stresses.

This neglect is common enough in the older structures, and the fault is a serious one, although the stiffness of the track rails and that of the ties tend to distribute the load and thus reduce the bending.

5.—Insufficient Bracing on Curves.

Too often in the older structures the curved portions of the line are no better braced than are the straight portions. A substantial system

of lateral bracing on curves extending over the entire width of the structure and carried well into the tops of the columns adds greatly to the rigidity of the structure, and, consequently, to the life of the metalwork.

6.—Insufficient Bracing between Adjacent Longitudinal Girders.

The function of the bracing between longitudinal girders is an important one, for it is the first part of the metalwork to resist the sway of trains. Not only should the top flanges of adjacent girders be connected by rigid lateral bracing, but the bottom flanges should be stayed by occasional cross-bracing frames, one of the latter being invariably used at each expansion end of each track.

7.—Pin-Connected Pony Truss Spans and Plate Girders with Unstiffened Top Flanges.

These defective constructions are noticeable in some of the older lines, but, fortunately, not often in the newer.

What the ultimate resistance of the pony-truss structure is no man can tell without testing it to destruction; but in the opinion of most engineers it is much less than it is assumed to be by those designing pony-truss bridges.

8.—Excess of Expansion Joints.

Too many expansion joints in an elevated railroad are nearly as bad as too few. In the former case the metal is overstrained by the vibration induced by the lack of rigidity, while in the latter case it is overstrained by extreme variations of temperature. There are elevated roads in existence with expansion joints at every other bent, and there is one with them at every bent. For long spans there should be expansion provided at every third bent, and for short spans at every fourth bent.

9.—Resting Longitudinal Girders on Top of Cross-Girders Without Riveting Them Effectively Thereto.

This is by no means an uncommon detail, especially in the older structures. It is conducive to vibration, and its only advantages are ease of erection and a cheapening of the work by avoiding field riveting.

10.—Cross-Girders Subjected to Horizontal Bending by Thrust of Trains.

The resistance that can be offered by a cross-girder to horizontal bending is very small; nevertheless, cross-girders are rarely protected from the bending effects of thrusts of trains. What saves these cross-girders from failure is the fact that continuity of the track tends to distribute the thrust over a number of bents. Nevertheless, it is not legitimate to depend on this fact, for, especially on sharp curves, the tendency is to carry the thrust into the ground as directly as possible. In the author's opinion the only proper way to provide for this thrust is to assume that 20% of the greatest live load between two adjacent expansion points will act as a horizontal thrust upon the columns between these two expansion points; and all parts of the metalwork should be proportioned to resist this thrust properly.

By running a strut from the top of each post diagonally to the longitudinal girder at a panel point of its sway bracing, the horizontal thrust is carried directly to the post, and a horizontal bending moment on the cross-girder is thus prevented. Such construction should invariably be used where the conditions require it.

11.—Cutting Off Columns Below the Bottom of Cross-Girders and Resting the Latter Thereon.

This style of construction, which until lately was almost universal, is extremely faulty in that there is no rigidity in the connection, and the column is thus made more or less free-ended at the top.

It has been said that no harm is done to the column by making it free-ended, as it can then spring better when the thrust is applied. Unfortunately this reasoning is fallacious, because the few unfortunate rivets which connect the bottom of the cross-girder to the top of the column tend to produce a fixed end, and are, in consequence, racked excessively by the thrust of the train. In all cases the column should extend to the top of the cross-girder and should be riveted to it in the most effective manner practicable.

12.—Paltry Brackets Connecting Cross-Girders to Columns.

Brackets are often seen composed of a couple of little angles and attached at their ends by two or three rivets. Such brackets are merely an aggravation, and are sure to work loose sooner or later. Although

it is impracticable to compute the stresses in this detail, nevertheless, good judgment will dictate the use of solid webbed brackets riveted rigidly to both cross-girder and column so as to stiffen the latter and check the transverse vibration from passing trains.

13.—Proportioning Columns for Direct Live and Dead Loads and Ignoring the Effects of Bending Caused by Thrust of Trains and Lateral Vibration.

The practical effects of this fault can be seen to best advantage by standing on one of the high platforms of one of the elevated railroads in New York City. The vibration, by no means small, from an approaching train can be felt when it is yet at a great distance. Some may claim that this vibration is not injurious; but they are certainly wrong, for what does it matter so far as the stress in the column is concerned whether the deflection be caused by vibration or by a statically applied transverse load, so long as the amount of the deflection is the same in both cases. It takes metal, and considerable of it, to make columns strong enough to resist bending properly, and a sufficient amount should be used to attain this end.

14.—Omission of Diaphragm Webs in Columns Subjected to Bending.

If the diaphragm web be omitted in such a column, reliance must be placed on the lacing to carry the horizontal thrust from top to bottom. But even if the lacing figure strong enough to carry it, which is unusual, it is wrong to assume it so, for the reason that one loose rivet connecting the lacing bars will prevent the whole system from acting, as will also a lacing bar that is bent out of line. Decidedly every column that acts as a beam also should have solid webs at right angles to each other.

15.—Ineffective Anchorages.

On account of both rigidity and strength every column ought to be anchored so firmly to the pedestal that failure by overturning or rupture would not occur in the neighborhood of the foot, if the bent were tested to destruction. The flimsiness of the ordinary column-foot connection is beyond description.

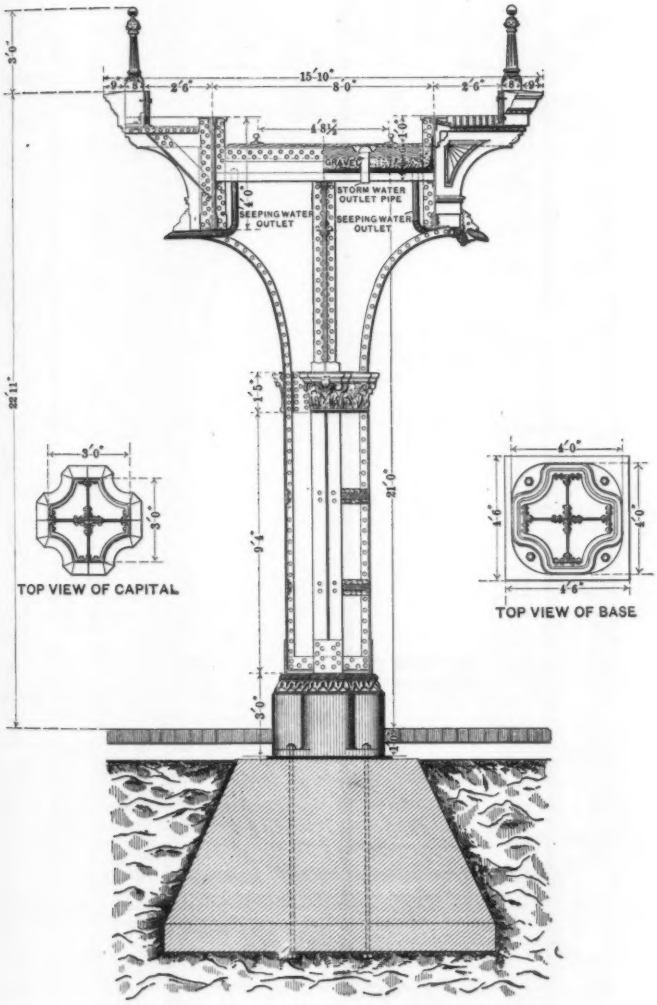
3'0"
15'10"
9"
2'6"
8'0"
2'6"
9"
4'8½"
1'6"
GAS
STORM WATER OUTLET PIPE
SEEPING WATER OUTLET
SEEPING WATER OUTLET
22'11"
1'5"
21'0"
9'1"
3'0"
3'0"
TOP VIEW OF CAPITAL
4'0"
4'6"
4'0"
4'6"
TOP VIEW OF BASE

FIG. 25.

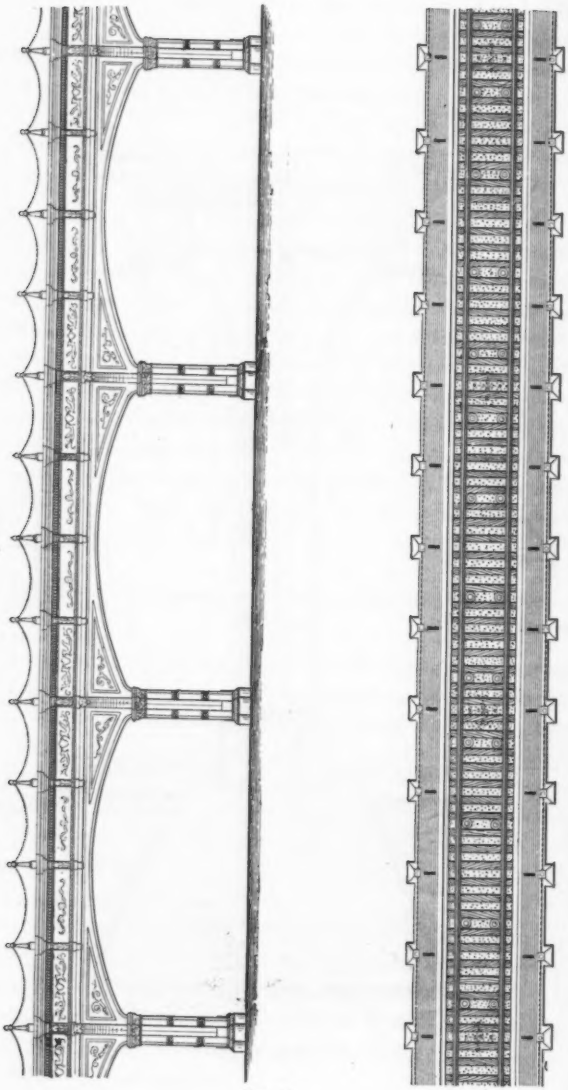

FIG. 26.

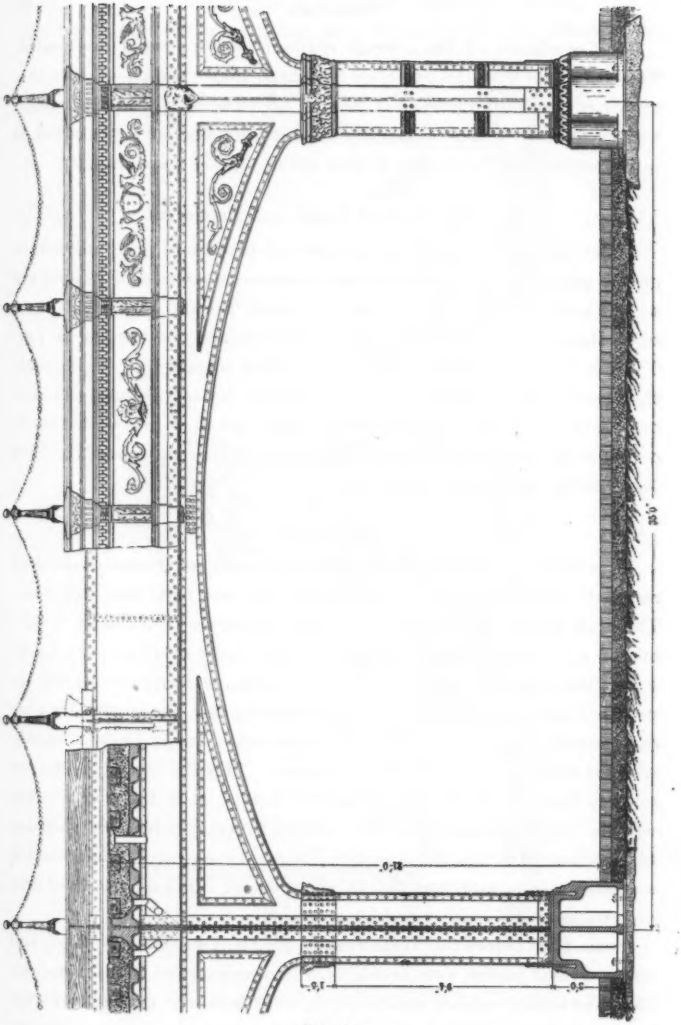

FIG. 27.

16.—Column Feet Surrounded by and Filled with Dirt and Moisture.

The condition of the average column foot is simply deplorable. This is caused by failing to raise it so high above the street as to prevent dirt from piling around it, and by omitting to fill its boxed spaces with concrete. When rusting at a column foot is once well started, it is almost impossible to stop it from eating up the metal rapidly.

17.—Insufficient Bases for Pedestals.

False ideas of economy on the part of projectors and indifference on the part of some unscrupulous contractors occasionally cause the use of pedestal bases altogether too small for the loads that come upon them, especially where the bearing capacity of the soil is low. The result is sunken pedestals and cracked metalwork. In figuring the pressure on the base of the pedestals it is not sufficient to recognize only the direct live and dead loads, but it is necessary also to compute the additional unequal intensities of loading caused by both longitudinal and transverse thrusts.

Æsthetics.

In relation to æsthetics in the designing and construction of elevated railroads something may be said, although but little has been done. The extra cost of decorating an elevated structure is certainly considerable, and on this account projectors are chary of attempting to do more than make the work strong and durable, preferring to let the appearance take care of itself. Notwithstanding this, the careful designer can generally manage to make his construction more or less sightly without adding materially to the expense. This the author attempted to do in both the Northwestern and the Loop. It is for others to say whether he has succeeded or not. At the Diversey Street and Sheridan Road crossings of the Northwestern Elevated some extra ornamentation was compulsory, so it was put in at increased expense; but elsewhere no extra money was expended on appearance.

Some time before the Northwestern Elevated was contemplated, and while several parties were trying to obtain concessions for a down-town loop, the author made a special study of an æsthetic type of structure for this locality, in which the consideration of expense cut no figure. The result of his studies is shown in Figs. 25 to 29, inclusive, Fig. 25

being a cross-section of such a structure, Fig. 26 a plan and elevation of a single-track railroad, Fig. 27 a side elevation showing some of the details of construction, Fig. 28 a cross-section of a street with a

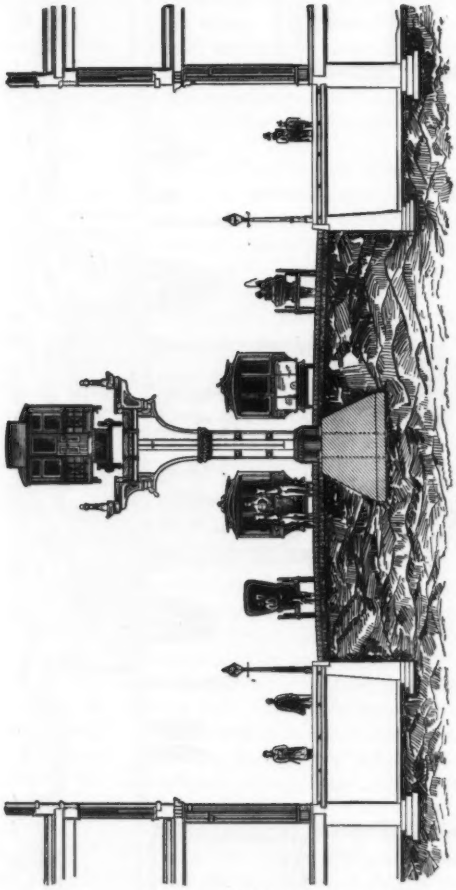

FIG. 28.

road of this type, and Fig. 29 a cross-section of the same road with a double-track elevated railroad. These designs involved not only appearance, but comparatively noiseless operation and freedom from

dripping of water on the people beneath the structure. Although no line was built according to these drawings, they have, notwithstanding, proved of practical utility in several ways; and the author now

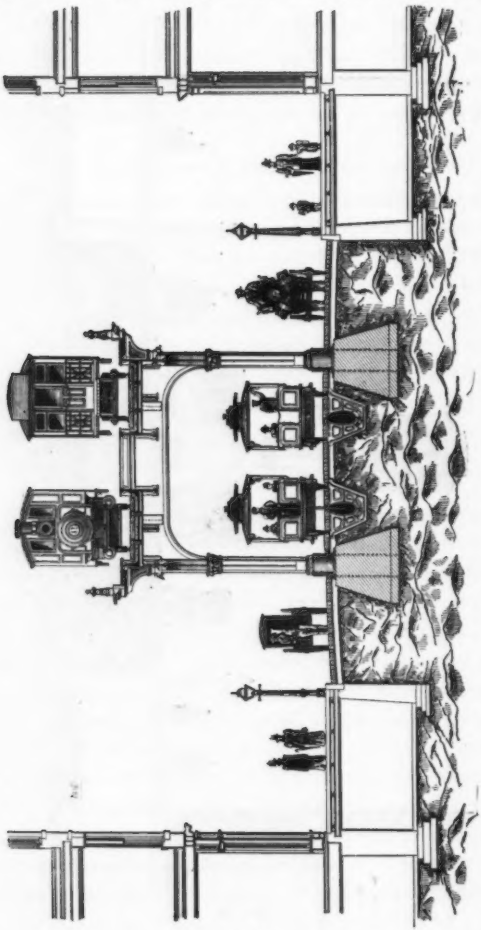

FIG. 29.

offers them to the engineering profession as his idea of what an elevated railroad for a large city should be where expense is no object and where appearance is the great desideratum.

DISCUSSION.

O. F. NICHOLS, M. Am. Soc. C. E.—Elevated railways are continuous bridges on which the loads are lighter but more frequently applied than on ordinary bridges. No special inspiration is required for their design. If they are built strong enough; if, since they cannot be made beautiful, it is possible to avoid making them ugly; if they are built to suit public convenience and at relatively low cost—then about all has been accomplished that lies in the mind of man to do for the ordinary elevated railways. Mr. Nichols.

It seems that much of the structure treated of in the paper is for four-track service and some of it on private property. The four-track system, like the loop system, is theoretically perfect, and yet seldom used in practice. New York City is probably the only place in which a four-track elevated railway would be bound to be successful, and where four columns under four tracks would be necessary. Designs 3, 6, 7, 8, 9 and 13 are all quite familiar as having been considered, in their essential features, in the studies made for the Suburban Rapid Transit Company of New York City in 1886-87.

For a railway on private property and where the space under the rails cannot be utilized for business purposes, as in cities like Chicago and New York, it seems the better way to build a viaduct; to surround the plot with a retaining wall of concrete and fill in with dirt; then place girders over the cross streets and lay the rails. An estimate made in 1888 showed that such a railway could be built cheaper than the structures considered in the paper.

There have been a number of types of foundation for elevated railways. In no place has the peculiar aversion to concrete been more notable, and in few instances has its use been more satisfactory. The several types of foundation used on the Brooklyn Elevated Railroad are shown in Fig. 30. The reduction in cost, corresponding with the changes in form and material, has been notable, passing from $190 each in 1885 to less than $90 in 1893. It will be seen that the type D, adopted early in 1892, is the one copied in the studies now under discussion. The author has, however, missed the true spirit of the design, and, misled by his column theory, has misused this really serviceable and economical foundation.

In securing the column to the foundation the author repeats, he says, the fastening he used in Sioux City in 1891; he certainly duplicates the fastening designed for the Union Depot shed in St. Louis.

If one were anchoring to solid rock or to massive foundations and resisting much greater stresses, these lugs might be necessary, but when, as in the sketches, 40 000 lbs. of tensile strength in anchor bolts is opposed to 13 000 lbs. of concrete, and the bolts are doubled for assumed extra stress, while the concrete mass remains the same, the

Mr. Nichols. lugs have a questionable value. This fastening keeps the bolts too near the center of the foundation, makes the resistance to rocking depend too much on the stress in the bolts, and is needlessly awkward and expensive.

A striking feature of the designs in the paper is the distribution of material in the columns themselves, in their connections and in the lateral bracing, and in the complex machinations necessary to endeavor to utilize this material. Indeed a series of troubles arises from the opinion that "20% of the greatest live load between two expansion points will act as a horizontal thrust upon the columns between these expansion points." This is pure fiction; it is not even empirical. There is nothing to justify it. Even the emergency stops in the air-brake tests do not give much more than 10% of retardation, measured at the rails. If the trains were skidded without wheels, the retardation would hardly reach the figure named. The dynamometer rarely shows more than 4 000 lbs. as the pull necessary to start an elevated train, and little, if any more, is needed to stop it. Then this thrust is not concentrated or limited in its action to a few feet of structure; it is spread through the rails and track system and structure generally to the next curve. The actions of the several trains counteract each other to a certain extent, and the net effect may possibly correspond to a pull or thrust at the rails equal to 3% of the total moving load on a half mile of structure and would be distributed over about a hundred columns.

There is a phenomenal continuity in these structures. It is impossible to close up an expansion joint except by expansion, which never amounts to as much as the ordinary theoretical requirements, because provision is made for excessive ranges of temperature. Owing to the continuity of the structure there is, in practice, very little lateral stress on the cross-girders, even in extreme cases and on curves. The older builders fixed the base of the column, and left the top free to vibrate; the more recent structures have the base of the column held and the top firmly fixed to the transverse girder; as a consequence, the stiffness of the column is brought fully into action and is then generally sufficient to resist the slight tendency to vibration. The recent structures do not vibrate, and have been likened to a common table, in which the legs are securely fastened to the top.

The entire effect of the extension of the lateral system beyond the longitudinal girders is to fix the columns partially at the top. Unfortunately the sketches do not give a clear idea of the details of construction; it would seem, however, as if none of the connections of the columns to the girders are either very simple or thoroughly effective.

No one has ever made a very satisfactory column from I-beams. The Z-bar is somewhat better for column construction, but both sections are unsatisfactory when it comes to connections with girders

Mr. Nichols.

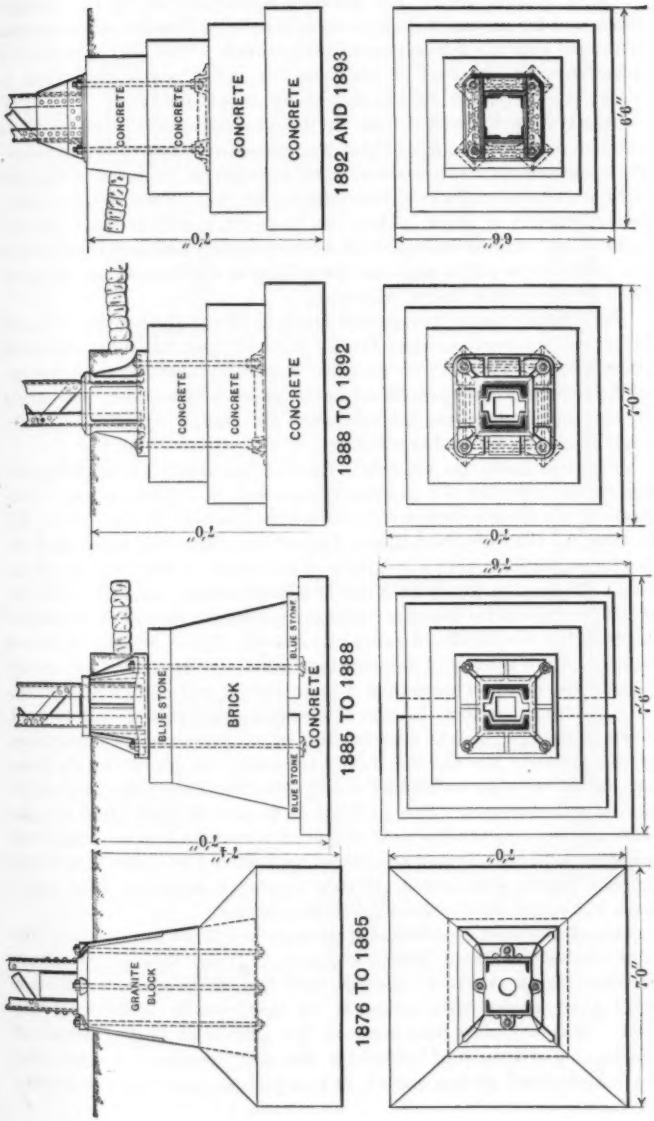

Fig. 80.

Mr. Nichols. or with column feet. The author's condemnation of the straight brace and his unqualified approval of the curved bracket are somewhat irrational and will not be generally approved. The curved bracket is unsatisfactory, because it professes so much and accomplishes so little; it is ugly, and, unless very heavy, it is ineffective.

Far too much stress is laid on the necessity for a web plate in a column, especially in a direction transverse to the axis of the structure. It is unnecessary to consider wind pressure, as such, in connection with an elevated railway of the ordinary height. There are, of course, lateral stresses to meet. They are, however, generally quite indeterminate, and may be fully provided for by simply fixing the column to the cross-girder at the top, and providing a double-riveted lacing of the column in this, lateral direction.

It certainly seems strange that Designs 12 and 13 should have much larger column sections than Design 3, which may easily have twice as great a load. This all follows quite logically, however, from the use of the column theory prescribed in the paper. It would be interesting to see, and weigh, the lateral brace for Design 3, when properly made to satisfy this column theory.

The expansion pocket (Figs. 8 and 9) has nearly all the defects of the old strap pocket of a generation ago, and is, constructively, a corruption of a pocket designed by Theodore Cooper, M. Am. Soc. C. E., in 1886, for the Suburban Rapid Transit Company, and since used on the Brooklyn road, with a reduction of the length of the lever arm of the load. Expansion joints need not be placed nearer together than 200 to 250 ft.; the latter distance was used latterly in Brooklyn, the joints occurring at the middle of every city block. These structures do not reach the high ranges of temperature generally assumed, and rarely expand and contract more than $\frac{1}{2}$ in. in 100 ft., and often not so much.

It is important that the cost of elevated structures should be kept down, although there is a possibility of exaggerating the importance of this matter. For the New York City roads, the interest on the present cost of stronger structures would constitute less than 15% of all annual expenditures. The problem is to get the best effect for the least money, *i. e.*, for the least weight of structure. It has been well said that existing elevated structures have plenty of material in them, but not rightly distributed. In this respect, the studies of the paper mark but slight advance over previous practice.

One of the most economical structures ever built was the stem line of the Suburban Rapid Transit Company. It was located on private property except at street crossings, and had but two tracks, although these were located with reference to the possible addition of two more. Masonry piers were used on the private property, instead of columns. Continuity of structures was not necessary or desirable; the longitudinal girders rested on iron plates, placed on the granite

Mr. Nichols.

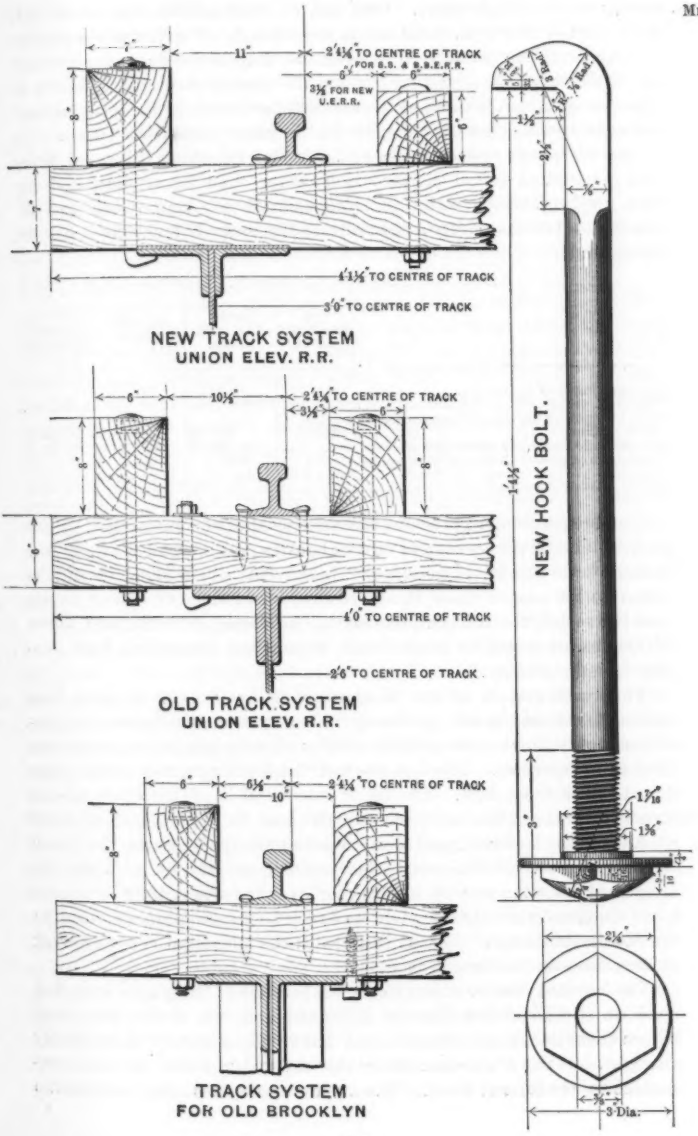

FIG. 31.

Mr. Nichols. coping of the brick piers. One end of each girder was fixed, the other slotted over ¾-in. bolts set in the coping. There was absolutely no vibration; the bents were substantial, imperishable and economical; the cost of the structure for double track was about $35, and a type was designed estimated to cost $30 per lineal foot. The loading was nearly twice that provided for in the paper under discussion.

The following approximate data for the Brooklyn Elevated Railroad is based on actual construction rather than on studies, and excludes siding, yards, water, coaling and interlocking plant, and all stations, other than noted, and reduces the cost of structure to 3 cents per pound.

	Old Brooklyn Lines.	Later Union Lines.	Sea-Side Lines.	Fulton Avenue Extension.
Average length of spans	44.7 ft.	50.9 ft.	52.5 ft.	
Weight of structure per lineal foot	870 lbs.	1 050 lbs.	1 130 lbs.	950 lbs.
Cost of structure per lineal foot, including foundations	$34 70	$36 50	$37 40	$32 00
Cost per mile, including passenger stations		308 000 00	286 950 00	213 900 00
Percentage of cost of bents to cost of spans	75%	69%	65%	

The length of span is about the same as that recommended by the author, but the percentage of cost of bent to cost of span is much less. If the "true theory of economy" is correct, about 30% should be added to the cost of these Brooklyn bents, and since this must be put into the metal, the foundations being the same, it would add about 12 000 lbs. of metal to these bents, which has, heretofore, been considered unnecessary.

The track system of the Manhattan Railway seems to have been accepted without much question. This system illustrates the persistency of minor errors and the ability of individuals to perpetuate their idiosyncrasies. The ties are not thick enough, nor is the outer guard-rail wide enough. The inner guard-rail is of little use in new structures, other than to space the ties and to give a sort of moral confidence to the timid, and these are its principal uses in the recent Brooklyn lines. If the only objection to projecting nuts was the danger of tripping one up in walking over the track, they would not be so studiously avoided or yield so easily to the cuspidors formed by the Manhattan cups. Fig. 31 illustrates the principal types of track system used on the Brooklyn lines.

The beveled ties provided for in the studies of the paper were first used on the Brooklyn lines in 1889, and had, no doubt, been used before that time, if not on elevated railways. They are theoretically all right, but the track-men prefer the old wedge block as more convenient to handle and reset. The author apologizes for a compromise

between theory and practice in using low elevations of the outer rail on curves, and says, "experience in operation alone will tell whether the decision of the company's engineers in the matter is correct." There need be no uncertainty on this score; these low elevations have been in use on all elevated railways from the beginning. There is no compromise with theory, since the lower elevations correspond with the slower speed absolutely required on sharp curves to avoid unseating the passengers. Mr. Nichols.

It is unfortunate that the details of the longitudinal girders and their connections are not given in the paper, as there are indications that close adherence to the scholastic methods has led to the retention of some of the antique errors of girder construction.

The simpler an elevated railway can be built, the better; the smaller the number of parts and the simpler the shape of these parts, the more satisfactory will the work be. No attempt at ornamentation should be tolerated, and the illustrations in the paper show this to be true. Ornament, to be good, must be necessary, and must be true. These conditions are not satisfied on elevated railways, except in the most rigorous simplicity of treatment.

The columns, in the æsthetic studies, are very large, and the spans inconveniently short. The arch span has no practical value. It does nothing that could not be better done without it; it is, in consequence, insincere and misleading and cannot be justified. It is intended to hide the girder, which really does the work, and is therefore a deluding member.

The æsthetic structure does not seem to require the heavy holding-down lugs and bolts of Designs 1 to 13; it will, perhaps, hold itself down. Here is, indeed, a structure, Figs. 27 and 29, which does not require holding-down bolts; which could, in fact, be skidded along over thick ice on its feet without falling, simply because its legs are stiff enough and are well fastened to its body. In this respect it sustains the recent practice in the East, if it does not fully satisfy the theories of the paper.

HENRY B. SEAMAN, M. Am. Soc. C. E.—In studying the requirements and the necessary expedients of an engineering problem, and in making the usual examination and research for precedent, many features will be found which indicate the influence of extraneous conditions over which the engineer has no control. This may be considered to have been the cause of such details in elevated structures as the use of flat plates for the main compression diagonals of lattice girders, or the construction of cross-girders with inclined end-posts, and with no other column connection than that afforded by an iron casting; but, though such details may, indeed, teach how not to do it, to say there are no other lessons to be learned from these structures is to forget that when first constructed some twenty years ago, Mr. Seaman

Mr. Seaman. they were unprecedented, and their better and more successful features have become so blended with general practice that even the examining engineer may fail to recognize the very source of his better information. These elevated roads, after twenty years of service, under loads exceeding those for which they were designed, show no indication of such deterioration as would justify the prediction of the author that they will eventually be reconstructed because of their faulty details.

There are several features of these elevated roads, which are worthy of consideration by those engaged in the most recent practice, and one of these is the effect of the longitudinal thrust of stopping trains. The use of the coefficient of 20% is extreme, even on a purely theoretical basis, as an examination of the tests of efficiency of air brakes will show. These tests, made under exceptionally favorable circumstances, show a resistance of about 15%, and when it is considered that the compact wooden floor system distributes such force indefinitely, it may be doubted if the resulting strains are of any considerable importance. Vibration must occur so long as iron has elasticity, but that such vibrations produce excessive strains, or in any way injure the structure, is not indicated by experience. If the vibrations are unpleasant, the remedy is to build stations and platforms upon separate foundations, with no connection to the main girders.

The speaker had already discussed the use of steel.* Though the exigencies of manufacture have practically eliminated the general use of fibrous wrought iron, it is reassuring to note the gradual progress toward a soft steel on account of its greater uniformity and freedom from hard spots. It seems to be the growing opinion among engineers, that the use of high or medium steel so increases the contingencies of failure, due to hardness, that a decrease of section is not warranted.

The shop coat of paint should, in the speaker's judgment, be one which will not conceal defects of manufacture, and for that reason he advocates the use of pure boiled linseed oil; but for a permanent coat of paint, there is probably nothing much better than red lead, unless experience should prove that carbon paints afford better protection against locomotive fumes. Some time ago, while examining a railroad bridge which had oxide of iron paint on compression members, and lead paint on tension members, both applied about four years previously by the same painters, the oxide of iron showed heavy scales and rust, while the lead was still in perfect condition.

In rail sections it would hardly seem necessary to go beyond those recommended by the Committee of this Society, which was composed of members of special experience, and whose report was the result of extended deliberation.

* *Transactions*, Vol. xxvi, p. 230.

Mr. Seaman.

The author's device for securing a truly fixed base of column is a good one, but the cast-iron bases of the New York roads have been entirely efficient, and in these cases the anchor bolts extend nearly to the base of foundations, instead of half way through, as the author shows. The detail of expansion joint is likewise thoroughly scientific, and a similar device has been extensively used in the vicinity of New York with very satisfactory results. The old style of pocket, formed merely of a bent plate, has, at times, proved weak at the bend.

The estimates of cost presented by the author are extremely interesting and valuable, but should not be considered with undue refinement, without the details on which they are based. For instance, Designs 6 and 7 are stated to be alike, except the additional brackets on No. 6, yet the estimate for each is the same; also, Design 8 has cross-girder strains and brackets, yet it is said to be less expensive than No. 7. Again, in the comparison of plans, he places the four-column structure on the same basis as that with two columns, though he does not state whether or not he has considered the fact that the four-column structure would receive its maximum column load from each train that passes over it, while the two-column structure would practically never receive such strain.

While his brother engineers may differ from him in a number of details, it is not intended to detract from those main features of the author's paper which are beyond criticism, and for the presentation of which all are indebted. He is likewise to be congratulated upon receiving the endorsement which has enabled him thus to adhere to the most advanced practice.

Mr. Clarke.

T. C. Clarke, Past-President Am. Soc. C. E.—The author gives a list of sixteen "essentials" to good elevated railway construction. Having laid down the law, he went on a tour of observation to see if it had been followed. The results were unsatisfactory. He went believing "that the methods in vogue for constructing elevated railways were radically wrong," and came back having accumulated "a great mass of information showing how not to do it." If he had carefully examined and correctly reported the condition of the Second Avenue structure of the Manhattan Elevated Railway of New York, he must have admitted that it conforms in general design to all of his sixteen "essentials," although in detail there are many differences.

The speaker took direct issue with the author's sweeping statement, and maintained that this structure, although designed twenty years ago, is not radically wrong, and has by its performance shown that it is not. The columns are of Phœnix section, but stronger than the section designed by the author. The foundations and their attachment to the columns are much better calculated to resist bending strains on the columns, and as there are none, it is perfectly proper to stop the columns at the bases of the cross-girders. That they are

Mr. Clarke. none the worse for this is evident from the fact that there is no perceptible vibration for approaching trains, whatever may be the case elsewhere. The Second Avenue girders have "no connecting plates between the diagonals and chords" and have fewer rivets than the author believes to be proper, but it is a matter of fact that after seventeen years' service under a heavy traffic there are few or no loose rivets.

By the courtesy of Mr. Fransioli, General Manager, and Mr. Waterhouse, Chief Engineer of the Manhattan Elevated, the speaker was able to give the following interesting statistics as to the Second Avenue structure:

Age, 17 years. Length, 7.4 miles. Total cost of repairs to structure, not including track and painting, $40 613 23; per year, $2 390; per mile per year, $319. Cost of repairs per ton of structural iron in 17 years, $1 39, which is about 2% of the original cost. The total tonnage passing over this structure in 17 years is 252 356 693 tons.

Practical men would call this good design and good construction, however it may be criticised.

The expansion joints and the entire floor system of the Second Avenue structure have been closely imitated by the author, and the speaker was able to agree with him so far. He also agreed with the author where he says that holes in riveted work should be punched smaller than the diameter of rivets, and reamed to a greater diameter. Either this or drilling is essential to first-class work. The speaker specifies it himself for swing-bridges and long spans. Whether it should be insisted upon for elevated railway work he has some doubts; it would, perhaps, be better to put the extra cost of reaming into increased quantity of metal.

The Second Avenue structure was not reamed, but it is unusually massive. Its weight per foot for two tracks, the posts and cross-girders being designed for four, is equal to that of the author's four-track structures. It is believed that its durability is due in a great measure to the low strains and large areas of metal, as well as good workmanship.

Mr. Crehore. WILLIAM W. CREHORE, Assoc. M. Am. Soc. C. E.—The author's statement as to the importance of good details and workmanship in elevated railroad structures is certainly commendable. There may be honest differences of opinion among engineers as to the comparative merits of two or more styles of detail to perform a given duty, but there are certain well-recognized principles which have been proved by experiment and experience to be fundamental in connecting and detailing the parts of a structure so that the full strength of each member is available when needed. That these principles either were not thoroughly understood or were not deemed of sufficient importance by the builders of elevated railroads ten or twenty years ago is very much

in evidence in New York. The speaker had no more intimate knowledge of the Manhattan elevated structure's condition than any one may obtain by riding over it or looking at it from the street, but enough is evident to show that the structure could be very much improved upon if rebuilt. Although the rolling stock now used is no heavier than was provided for by the designers, yet the live load is now a maximum, the wear and tear is continuous, and the speed of trains has been much increased, notably on curves. Then, too, the improvements in the air-brake during the last fifteen years have caused a substantial increase in the traction load. It was the opinion of the speaker that under these conditions no amount of patching can prevent a gradual decline in the factor of safety of the structure, and without wishing to arouse any undue apprehension, one might reasonably seek to know why, in a city that gives special attention to all other building construction, whose insurance companies inspect carefully and regularly the elevators in the tall buildings, and whose vigilance for the health and safety of the people is so practical and thorough in other directions, the elevated railroad structure which carries 500 000 people a day should be left, with no check except the occasional superficial inspection of the State Railroad Commissioners, entirely to the watchfulness of its own management, which in other matters is known to be not too particular. Mr. Crehore.

It will be argued and figures might be produced to show that the elevated railroads in New York have been remarkably free from accidents, having carried an enormous traffic during the last twenty years with practically absolute safety; all of which is true, being due partly to the very efficient handling of trains, and partly to the fact that the factor of safety of the structure is not yet used up. A chain is no stronger than its weakest link; the factor of safety of a structure is no greater than that of its weakest member or its weakest detail. A structure which is subjected to continual vibration and is never painted must of necessity be wearing out. It therefore becomes a matter of great interest to all who are directly concerned to know how nearly worn out the individual members and details of the Manhattan Elevated Railroad structure are.

CORRESPONDENCE.

Mr. Bouscaren. G. BOUSCAREN, M. Am. Soc. C. E.—Two points are brought out by the author which are specially worthy of discussion, viz., the selection of the grade of steel most appropriate to the class of structure under consideration and the desirability of a more extensive application of reaming in riveted work.

The denomination of medium steel generally implies a degree of hardness consistent with an ultimate strength of from 60 000 to 70 000 lbs. per square inch, with a ductility measured by an elongation of about 25% in 8 ins. The corresponding figures for soft steel are generally from 50 000 to 60 000 lbs. per square inch, and about 30% elongation.

Soft steel is a material eminently tough and ductile, the progress made in its manufacture leaves little to be desired in regard to uniformity in the qualities of products, and commands confidence in its ability to resist a considerable amount of rough treatment. It is manifestly superior to iron in most respects, and is rapidly taking its place in ship-building and boiler-making; it is without question well adapted to structures exposed to considerable vibration and impact, such as the deck members of railroad bridges in general, and all members of short-span elevated railroads in particular. The same degree of uniformity in quality cannot be claimed for medium steel at the present time; it may be obtained occasionally, but never with the same degree of certainty. Besides being a harder and less ductile material, medium steel is liable to extra hardness and brittleness in spots. Until it can be treated on the same footing as soft steel in point of uniformity, its use in the riveted members where exposed to sudden variations of stress, or to shocks incident to derailments or collision, will not afford the same degree of security as that of the softer metal. The examination of a railroad bridge fallen under a passenger train, presumably by the work of wreckers, has recently confirmed the writer in his views as to the use of medium steel in deck members. A notable feature of the wreck was a 60-ft. steel plate girder standing almost vertical with one end about 3 ft. in the ground. The only apparent injury to the girder besides the bent lateral angles at the end was in the bottom flanges, two of the four flange angles being cracked squarely across without any other deformation.

Steel of good quality is made by both the acid and basic process, the only marked point of difference seems to be that a lower content in phosphorus is practicable for basic steel than is the case for acid steel. Phosphorus being admittedly an objectionable element in steel, this consideration should seem to settle the question in favor of basic steel.

The writer is in hearty accord with the author in what he says in

Mr. Bouscaren.

regard to the desirability of reaming rivet holes in all kinds of material. It is a universal practice to specify that all rivet holes should match exactly and be of the exact diameter required for the hot rivets. There is no difference of opinion as to the importance of these conditions to the good quality of the work. Every one knows that they cannot be secured without reaming, yet the stipulation as to reaming is generally omitted to save cost. It seems to be one of those instances of puerile self-deception where the engineer, unconsciously, perhaps, seeks to obtain a certain desirable result without paying for it. It is hardly necessary to add that such attempts are generally failures. Every one will also admit that punching is a brutal operation, which seriously injures the metal, be it iron or steel, within a certain distance from the shearing surface. If flaws are objectionable in the body of a plate, they certainly are more so in the bearing surfaces through which all stresses are transmitted. Under the old assumption attributing the resistance of a riveted joint to the friction between the plates, developed by the contraction of the rivets, it was a matter of little importance whether the rivets completely filled the holes or not, and punched holes answered the purpose well enough, but they are inconsistent with modern practice, where rivets are treated as pins.

The superiority of reamed work is no longer a matter for speculation. Carefully made tests at the Watertown Arsenal as far back as 1882 showed that it could be depended upon for a gain in strength of about 15 per cent. This result has been repeatedly confirmed by later experiments. As the matter now stands, it is simply a question between good work and inferior work, and whether the extra cost of reaming is worth the additional security implied in the greater strength and uniformity of the work. These advantages acquire a special importance in short spans and decks of railroad bridges.

The use of Portland cement in the concrete for the substructure is a wise provision, especially for the upper part of the pedestals exposed to severe stresses and weather.

In view of the fact that the columns are expected to act as cantilevers anchored to the pedestals, and to resist by bending all horizontal forces arising from curvature, from the wind, and from changes of temperature, it would be interesting to know the maximum degree of temperature, the wind pressure assumed per square foot, the speed of trains assumed on curves, the maximum range of temperature from the initial position where there is no temperature stress, and whether any provision is made for easements at the ends of curves. If such provision is not made, a considerable percentage should be added to the centrifugal force for impact. It would also be of interest to know the units of working stress adopted for the different parts of the structure, and in particular for the columns with the combination of all forces acting together.

Mr. Rousseau. H. H. ROUSSEAU, Jun. Am. Soc. C. E.—In regard to the reaming of holes for shop rivets in soft or even medium steel, the writer believes that due consideration should be given to the average number of component pieces the rivets pass through, to the amount of wear and tear the structure has to withstand, and to the financial resources of the purchaser, before arriving at a decision in any particular case. If the benefit of removing, by reaming, material possibly injured is waived, the question becomes reduced to ensuring sufficient bearing area for the rivets in the most economical, and at the same time a satisfactory, manner. The proposition is not that rivets in unreamed holes have no value, but what is a safe and proper value to give them. The question is not one of vital importance to the safety and stability of the structure, being only to establish the comparative value of a rivet driven in a reamed hole $\frac{1}{16}$ in. larger than the cold rivet, and one driven in a punched hole, the mean diameter of which, according to general practice, is $\frac{3}{32}$ in. larger than the diameter of the cold rivet. Justly or unjustly, no distinction is now made between the two, and, at present, the purchaser has only a choice between unreamed work, which is condemned on account of the deviation of punching from mathematical precision, and upheld on account of its cheapness, and the reamed work of admittedly superior workmanship and higher cost, the rivet values being taken the same for both. If a relation can be once established between the two, then by decreasing the number of rivets for reamed work, the two classes of work will be put more nearly on the same plane, as far as theoretical requirements and cost are concerned. It is of interest to determine what this will amount to on a 50-ft. deck plate-girder span weighing 14 tons and costing, reamed, $60 per ton erected. The number of rivets in the span will be taken as follows:

Flange angles to web	925
Flange angles to cover plates	925
Stiffeners and web splice	400
Bed plates	50
Lateral bracing	300
Total	2 600

At $3 per ton, the average price given by the author, reaming costs $42, about 1.6 cents per rivet. Any change in rivet values would affect appreciably only the number of rivets in the flange angles, and for the change in total shop cost caused by a rivet more or less may be taken the cost of material plus laying off and punching, and driving the rivet. At 5 cents per rivet, 840 additional rivets could be driven before the cost of reaming would be equalled, and in one-third the time it would take to ream, and it would thus not be economical to ream unless a

rivet in punched work was worth less than about three-fourths a rivet in reamed work. The area of a $\frac{7}{8}$-in. rivet upset to $\frac{1}{1}\frac{1}{6}$ in., as in punched work, is increased over 20%, which excess is not considered in order to be on the side of safety. For a $\frac{7}{8}$-in. rivet upset to $\frac{1}{1}\frac{5}{6}$-in. in a reamed hole, there is less reason for disregarding the increased area of 14.8 per cent. Increasing the unit strain in proportion will cause a saving of 240 rivets in the flanges, which, at 6.6 cents, amounts to $16, over one-third of the cost of reaming. This may be stated as follows: Mr. Rousseau.

	Cost.	Per cent.
Punched work	$798 00	100
Reamed work, with increased rivet value	824 00	103.3
Reamed work, with ordinary rivet value	840 00	105.3

What is wanted at present is to know how long reaming lengthens the life of a structure or decreases its cost of maintenance. A practical experiment of the matter could be made on any railroad bridge having a number of spans of equal length, some spans being reamed and others punched, and by comparing results. The opinion is ventured that in general if the cost of a structure were to be increased 5%, better results would be obtained by expending this amount on more material than for reaming. To those who are not in favor of reaming, the objection is not that reaming is not a good thing in itself, but that it is not worth, to the ordinary purchaser, in prolonging the life and increasing the efficiency of the structure, what he has to pay for it.

HORACE E. HORTON, M. Am. Soc. C. E.—As to metal, material, and workmanship for elevated railroads, the writer does not understand the requirements are essentially different than for bridge work in general. It is interesting to note the modification in the ultimate strength of metal specified and used over a term of years. Thirty years ago iron of over 60 000 lbs. tensile strength was demanded; however, iron of 48 000 lbs. tensile strength was the accepted standard when iron went out of use for structures. Steel first used in structures was of 150 000 lbs. tensile strength; later, 80 000 lbs. seemed to be the favorite, and now the author shows the exact percentage of advantage in the use of 64 000-lb. steel. What is to be the ultimate strength demanded for structural steel in the future can only be a matter of conjecture, but the writer thinks it reasonable to conclude that within a short period steel for structural work will be demanded of under 56 000 lbs. tensile strength. While in the past steel-makers have not been prepared to furnish steel of this character, and it now can only be had at increased expense, indications are that this extra cost will be modified or eliminated at an early day. Mr. Horton.

No one at this time will offer to use 150 000-lb. steel, and it is difficult to find an engineer who would justify himself in using three-quarters the bulk of 80 000-lb. he would of 60 000-lb. steel to accom-

Mr. Horton.

plish a definite result. The author uses 7% less material of medium steel than he would of mild steel, and nearly offsets the estimated advantage by increased cost of manufacture. If his estimate is modified to fit the market as it is at this time, that is, manufactured structural material, f. o. b. Chicago at 2 cents instead of 3 cents per pound, as he indicates, his estimate of the cost of reaming would be from 5 to 10%, or an average of 7½%, somewhat in excess of the advantage named for extra strength.

The writer does not believe any such objection exists in the minds of manufacturers to reaming as indicated by the author. That they are not fully advised as to the exact cost is undoubtedly the fact. Whether it is $2 per ton, the minimum named, or $7, the maximum asked, has not been proved. Further, the manufacturer finds himself at a loss in tendering on work which demands reaming, to judge whether it is to be accomplished by mental science process or by physical act. While reaming has been specified for most steel bridge work for the past fifteen years, many of the manufacturing concerns of the country are in shape to do reaming only by the method which the author terms "humbug," while others are prepared to ream with drills from one-tenth to one-fifth the capacity of their rivet shops; hence, the conclusion is irresistible that a very large percentage of the reaming previously specified has been accomplished by an incantation pronounced over the punching machine.

The author proposes to ream rivet holes $\frac{3}{16}$ in., that is, $\frac{3}{32}$ in. on each side of the hole, as a remedy for misfits of $\frac{1}{32}$ in. named as common in punched work. Evidently he has been unfortunate in his acquaintance, and further seems to overlook the fact that a concern which has rivet holes misfit by 1-8 in. will do slovenly work even when reamed. The writer's observation leads him to conclude that the punching of rivet holes and the driving of rivets is not more careless than much criticism. He has never seen a rivet go loose in service where the design was rational and there was any reason to expect satisfactory results from the rivet, and further diligent inquiry among those whose observation has been the broadest verifies his experience as stated.

The reaming of rivet holes in metal work in the future must depend on the disposition of the proprietorship to pay for such reaming. The case where the ownership, as described in the paper, was ready to pay for reaming, in fact insisted on having it done, turns on the further fact that the ownership was advised by its engineer that less reamed material would furnish a more valuable structure at less aggregate cost. It would be more instructive if there was an example of where proprietorship had shown a readiness to pay for the extra cost of reaming, where the extra cost would be 7½% of the value of the manufactured material, and the advantage lie only in an improvement in the

feelings of the engineer. Examples of this character would at once remove all objection on the part of manufacturers to reaming, but when the argument is based on building a better structure with a smaller quantity of less reliable material, the writer believes proprietors, manufacturers and engineers all have reason to be sceptical, and he doubts if practice will follow the suggestion. Mr. Horton.

There are at this time three elevated roads operating in the city of Chicago, all of recent construction. Two of them have been reorganized, and the third is in the hands of a receiver. A fourth has considerable work of construction done, and the daily press states that it is negotiating for funds to carry the enterprise to completion. All have to meet the competition of well-equipped cable and electric street car lines as well as surface railroads, all of which competition would naturally point to the construction of elevated lines in shape to serve their patrons with the least discomfort, placing their cars as near the street grade as possible.

The author shows a structure with an elevation above street surface at the base of the rail of 21 ft., which is essentially the elevation of the roads built and projected, while the city requires a clearance of 14 ft. This makes it possible to use an elevation of 15 ft. to the base of the rail; that is, the entire system of Chicago is built 6 ft. higher to the base of the rail than the requirements of the city call for, while three of the four lines projected and built are largely on private right of way. The extra expense of building through bridges for street and alley crossings would have been balanced by the decreased cost of construction of the other parts of the line, while such parts of the line as have been built in the street would have been either through construction or carried on single columns on the curb line, where girders could have been placed under the rails. This would require modification of ordinance, and be attended undoubtedly with some difficulty, but it would be not at all impossible. Further, curves and intersections in the streets would be attended with greater difficulty than by the present method of construction, as undoubtedly many cases would develop where the tracks would have to be suspended from overhead girders.

It is also apparent the floor of car might readily be 3 ft. from the base of the rail instead of 4 ft. Thus the elevated structure would fulfil the demands of the city for a clearance of 14 ft. and be only 18 ft. to the floor of the car, instead of 25 ft. How much of the financial distress, past, present and to come, the useless 7-ft. elevation has and is to cause is entirely a matter of speculation. It surely requires energy on the part of the patrons of the road to overcome it. It cannot be demonstrated that the elevated structures would have been a great financial success if 7 ft. lower. That they would have had a more nearly even chance is obvious.

Mr. Mogensen.

O. E. MOGENSEN, Assoc. M. Am. Soc. C. E.—An elevated railroad presents in its general character and in its manner of construction more uniformity than most steel structures, as the single members and typical details once adopted are to appear over and over again throughout the work. Hence a thorough and detailed study, such as has been made by the author, is of great importance in order to obtain the strictest economy in construction, manufacture, and maintenance without sacrificing strength and rigidity in design. That the preliminary work had been successfully carried out by the author, and that every detail had been carefully considered when the contract was let, is shown by the fact that the last portion of the structure now erected, as well as the first, stands as a true copy of the typical drawings on which the contract price was based, and from which the cuts are reproduced.

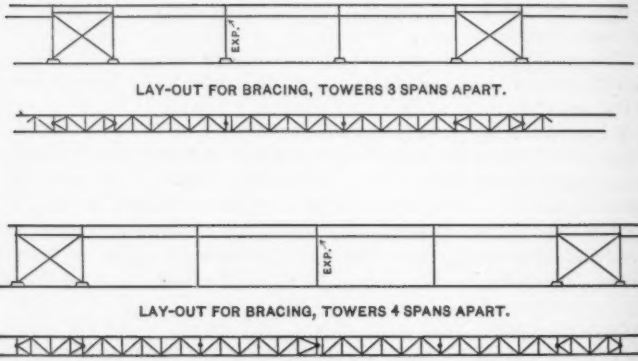

FIG. 32.

This is evident from the fact that only one alteration, even of minor importance, was made in the lateral bracing, which originally was designed as shown in Fig. 2.

From this general plan it will be seen that the longitudinal thrust from the girders is carried into the columns by a triangular bracing on both sides of each column. This was necessary in order to avoid the horizontal bending in the top and bottom flanges of the cross-girders due to temperature stresses. However, in detailing the cross-girders the section adopted for the flange angles was found to be sufficient to carry both the horizontal bending plus the strain due to the maximum live and dead load on the structure, for cross-girders spaced but one span length from the tower bents. The bracing was, therefore, changed as shown in Fig. 32, thereby simplifying the manufacture and the field work on the columns.

Mr. Mogensen.

It should be noted in this connection that the omission of the triangular bracing was made only in structures on tangents, whereas the structure on curves remained as shown in Fig. 2, with additional lower lateral bracing, as mentioned by the author in § XX.

In speaking of the riveting of work punched to full size, the author condemns the use of the movable air reamer used to enlarge eccentric rivet holes. In this connection the writer would state that it is a well-known fact among inspectors that less loose rivets are encountered in work punched to full size than in reamed or drilled work. This may be explained by the fact that the looseness of rivets driven through an irregular hole is much more difficult to detect than loose rivets driven through a perfect, cylindrical and smooth hole, as the crooked rivet naturally gives much greater friction to the irregular surface formed by the eccentric holes.

This is another good reason which speaks for the sub-punching and reaming or drilling in main members of structural work; whereas, punching to full size, when carefully done, will, in the writer's opinion, suffice for light work and for members of secondary importance.

The full value of sub-punching and reaming rivet holes in preference to punching to full size is somewhat impaired by the fact that the adjoining plates in long members may not come in tight contact with each other at the rivet holes. It is not seldom found that these voids are wide enough to allow the blade of a pocket-knife to pass between the plates close to the rivet. These voids are caused by the drilling. When the tool has passed through one plate and commences to pierce the other, the two plates spread enough to permit the steel shavings to locate between the plates around the rivet to a distance of 3 ins. from its center. The removal of such shavings is a very simple matter, which would hardly necessitate the loosening of the bolts, but which should be done in order to derive the full benefit of the reaming or drilling of rivet holes.

Among the various designs so thoroughly discussed by the author, a comparison between steel and wooden floor systems has not been taken into consideration. As the Northwestern Elevated Railroad, with the exception of a small portion of the line, occupies private property, it is hardly probable that any city restrictions would have excluded the use of a steel floor system, which for several reasons seems of advantage for a structure built so substantially and for which, without doubt, greater economy in maintenance and durability during operation have been considered of more importance than an imaginary saving in the first cost.

The extra cost of a corrugated floor above that of a wooden floor system of vulcanized timber is justified by the following advantages:

Mr. Mogensen. *First.*—When properly designed it will last as long as the main members in the structure.

Second.—As a lateral system it will increase the rigidity of the structure materially, and thus take the place of the upper lateral system, which is needed for the wooden floor system.

Third.—In case of fire from any of the adjacent buildings, destruction to the structure and interruption of the traffic might be avoided.

Fourth.—Cost of maintenance and inspection is considerably lower than that of a wooden floor system so heavily loaded.

Fifth.—Fifteen, thirty or forty-five years hence, yellow pine or equally good timber may not be had for the market price quoted to-day.

In using a corrugated floor the longitudinal girders may be raised far enough above the top flanges of the cross-girders to act as guard rails, which would necessitate a spacing of about 7 ft. 2 ins. center to center of the longitudinal girders.

The first cost of such a floor stands as about $11 10 per linear foot of structure to $6 28 per linear foot of structure for the wooden floor system, based on the price of $38 per 1 000 ft. B. M. for vulcanized timber in place, as quoted by the author. This would mean an extra cost of about 15% to be added to the total cost of the line, which is quoted as $32 65 per linear foot of line for Design 6.

If the life of the vulcanized timber be put at fifteen years, these figures show that in less than twenty-seven years the money expended for a wooden floor system would amount to the same as the entire cost of the steel floor, disregarding the greater cost for inspection and maintenance of the wooden floor system. It may be said that the steel floor directly supporting the rail would cause greater vibrations, noise and wear upon the structure than the wooden floor system. But has not the experience of recent years demonstrated the superiority of the steel floor system over the wooden floor system, which needs constant attention after a service of four to five years, which attention is especially dangerous on an electric elevated railroad, operated by the third-rail system?

Mr. Hall. Wm. M. Hall, M. Am. Soc. C. E.—The author's specification for fineness provides that 90% shall pass the No. 100 sieve. It is believed that most of the foreign Portlands will not pass this specification, although they are equal or superior to the best domestic makes. It would, therefore, be interesting to know if the foreign makes were excluded by this specification, or if the manufacturers shipped, or proposed shipping, cargoes of especially fine ground cement to meet the requirements. The specification for tensile strength appears to give a maximum as well as a minimum limit. The minimum in all cases is very low. Most specifications give only the minimum tensile strength, which, for briquettes treated as specified, is now usually placed between the figures following, viz.:

Mr. Hall.

Pure cement ...	7-day	briquettes,	between	400	and	500	lbs.
"	28	"	"	"	475	"	600	"
1 cement, 3 sand.	7	"	"	"	120	"	180	"
1 " 3 "	28	"	"	"	170	"	250	"

It has been considered not detrimental to a cement to show a higher tensile strength for short-time tests than any of the maxima given in the author's specifications, unless it was shown to recede later in strength. It is, therefore, not clear to the writer why they are given.

In no part of these specifications is the temperature of air or water mentioned. The temperature of both, however, is an important factor in the time of setting, and also in all other tests. Therefore the writer believes that the temperature of water for mixing should be accurately specified, and the temperature of air in the testing room approximately so.

Mr. Ostrup.

J. C. Ostrup, Assoc. M. Am. Soc. C. E.—In comparing the merits of the many excellent designs presented in the paper, the writer will confine himself to those of Design 1, Fig. 12, and to Design 10, Fig. 21. Some of the more important advantages in Design 1 are found in the fact that the short transverse girder for each track and its bracket and column are made in one piece in the shop, and that the web plate through these parts is practically continuous; its cheapness, costing about $11 200 less per mile; its greater rigidity and facility of manufacture and erection. For these reasons this design was adopted for the Northwestern Elevated Railroad, but over this design, Design 10 has, in the writer's opinion, one material advantage. It will be seen in Fig. 9 that the short transverse girder projects 3¾ ins., which, with the additional amount of projection caused by the rivet heads, is increased to about 4 ins., above the plane of the longitudinal girders. This feature is eliminated in Design 10, which would be a material advantage when placing the floor system or track work on the structure.

For various reasons, which are immaterial to this discussion, it is intended on all curves of the Northwestern Elevated Railroad and the Union Elevated Railroad to use beveled ties spaced 15 ins. center to center, and to place them radially to the curves. Local conditions have in most cases rendered it impossible to place the bents or transverse girders radially, and their direction is therefore at variance with that intended for the cross-ties. Consequently, it will be necessary to change the direction of all ties in proximity to the cross-girders, or to adze down the ties by 4 ins. where they cross the top flange of the transverse girders, both of which methods are undesirable. Even supposing that all the cross-girders could be located radially, the width of their top chord would, of necessity caused by local conditions, vary from 10 to 14 ins. As the ties are 8 ins. wide and

Mr. Ostrup. spaced 15 ins. center to center, this leaves a clear space of 7 ins. between two adjacent cross-ties. This space of 7 ins. would be anywhere from 10 to 14 ins. at every bent, and produce an irregularity which is also undesirable.

In regard to the merits of the braced towers, the author seems to have shown some unnecessary modesty in not describing their great and undisputed advantages more fully. On all elevated roads the expansion pockets are generally spaced about 150 ft. apart, with a clear opening in the pocket of from 2 to 4 ins., according to design and accuracy in the triangulation work, and, therefore, a structure of this kind forms a series of independent sections, each 150 ft. in length. The chief object in view, when designing every detail of an elevated railroad expected to pay interest on its invested capital, should be rapid transportation. With the utmost universal use of electric power for the competing surface cars, its financial life depends almost solely upon this point. Therefore, it is necessary to propel a train over this non-continuous structure at a rate of say 40 miles an hour, and to start and to stop the train as quickly as the traction will permit. All this causes a great amount of vibration. The idea of properly checking this vibration, which is greatly detrimental to the rigidity as well as to the life of the structure, seems to have been almost entirely overlooked heretofore, and is solved excellently and effectively in Design 1. Another highly commendable point in favor of this feature is the fact that these braced towers reduce to a considerable extent the total weight of metal in the structure, which reduction, according to the author, amounts to the surprising figure of 9 per cent.

Mr. Campbell. C. E. H. CAMPBELL, M. Am. Soc. C. E.—In the author's study of the elevated railroad question, it seems that he has almost exhausted the points of discussion himself by presenting some fourteen different designs and arrangements of structures, with comments thereon. As to the specifications and designs necessary for the construction of such structures, when certain requirements are fixed and conditions determined and the structural engineer takes hold of the case, the results are generally dependent on his knowledge and experience, assisted by information that he is able to collect from others who may be skilled in that line. The author seems to have pursued this method, and reached out further by investigating defective features in existing structures, and such endeavors to remedy defects cannot fail to improve production, if the man who prescribes the remedy knows all about the disease.

The author dwells at some length on the matter of reaming. From the engineer's standpoint, where the nearest possible approach to perfection is desired, his deductions cannot be denied.

From the manufacturer's standpoint, objections will be in inverse proportion to his facilities for performing this class of work. The

writer's opinion is that if any built member, whether in tension or compression, has assigned to it a fixed value of working stress per square inch, this fixed value is based upon the physical properties of solid, perfect and faultless material, and the joining together of the component parts of the member by rivets, bolts, welds, or any other method, should be so perfect in detail that there will be no defect in the member against which it is possible to provide. Punching acts in the nature of a force applied almost instantaneously, with power enough to tear or shear a hole through the metal. The part that is thus disrupted is torn, bent, bruised and evidently damaged for at least a small distance around the hole, and it is evident that those parts that are thus distorted cannot have the same effective strength per unit as the original sound piece. Further, if part of the rivet holes match and others do not, there must be an unequal straining of the particles of metal in the member, even if the rivets fill the holes fairly well. The writer has heard some manufacturers claim that if reaming is deemed necessary, then each piece can as well be reamed separately before assembling. This is evidently wrong, as the chance for bad matching of holes remains the same as before reaming. To produce perfect results, all component parts should be assembled before reaming. The results obtained by the use of portable reamers are somewhat questionable, depending to some extent on the intelligence of the workman handling the machine. The use of stationary reamers places results beyond question. Mr. Campbell.

Regarding longitudinal bracing and the vibration incident to the lack of it, the writer had an opportunity to observe this defect in the Sioux City elevated road, some 6 000 ft. in length, in which there was no provision whatever made for traction force, and dependence was placed only on the riveted connections between the ends of girders and columns. The vibration was plainly noticeable at a point 2 000 ft. from the moving train. What effect this will have on the connecting rivets remains to be discovered.

The question of painting metal in such a way as to preserve it for any length of time from the action of the elements has been the subject of considerable talk, with but small results. The custom of oiling metal at shops or mills produces no good results, further than protection from rust during manufacture and transportation. Oil is a poor foundation on which to spread the paint. The protective element in paint is the pigment, and the oil the medium by which it is applied. Therefore, if anything is put on the metal at shops or mills, it should be the best protective compound known.

The author takes occasion to mention the frequent practice of some bidders of attempting to throw discredit on the plans and specifications of the consulting engineer. The writer ventured the opinion that he who knows all about the disease is qualified to prescribe the remedy.

Mr. Campbell. While the author has diagnosed the case in question, he has encountered another kind of disease. This malady often gets a grip on engineers and proprietors of some manufacturing concerns, and they determine that the consulting engineer does not know what his employers want, but that they do. Therefore they attempt to ignore the engineer's designs by submitting "much superior" ones of their own special make. Such designs are generally made to conform to their individual shop practice and the most economical shapes rolled by their own mill, and the only object in view is cheapening the product to the manufacturer, and obtaining contracts with more profit than if taken on the engineer's specifications.

Mr. Osborn. FRANK C. OSBORN, M. Am. Soc. C. E.—The writer takes pleasure in heartily indorsing the paper, as a whole, but would like to call attention to a few points mentioned by the author, with the idea of emphasizing them. The first of these is the requirement in regard to providing "adequate means of transmitting the thrust of braked trains from longitudinal girders to columns without overstraining the cross-girders," and the proportioning of columns to "provide sufficient strength to resist direct load, bending from longitudinal thrust, bending from transverse thrust, and on curves bending from centrifugal loads." These features of design have frequently been lost sight of entirely, and their importance ought to be recognized fully, for the reason that the stresses requiring these provisions occur at every passage of a train. It should be borne in mind that any stress applied to such structures must eventually reach the earth, and proper provision ought, of course, to be made for its doing so.

In regard to the importance of good design, material and workmanship for elevated railroads, it seems that these requirements are, if anything, even more important than for ordinary steam railroad bridges, for the reason that trains are much more frequent, and they are being constantly stopped and started at stations which are comparatively short distances apart, making the punishment to which an elevated railway is subjected much more severe than that of an ordinary railway bridge.

The writer agrees with the author in the preference for medium steel with sub-punching and reaming over soft steel without the reaming. A gain is effected on account of the greater strength of the medium steel, and the reaming is certainly advisable, as it removes the injured metal in the immediate vicinity of the hole and makes a better job from a workmanship standpoint. Objections to reaming and drilling appear to come principally from manufacturers operating small plants without facilities for doing this kind of work. Some manufacturers, however, although fully equipped to do the work, are in the habit of bidding on work for which reaming is specified and then doing their utmost to have the reaming waived, solely with the

view of increasing their profit. The practice of a number of manufacturers of always endeavoring to have modifications and changes made in plans and specifications and solely with the idea of diminishing the cost of the work to themselves, without any advantages whatever to the purchaser, is one hardly to be recommended. This policy, in a number of cases known to the writer, has led to the placing of the contractor at a positive disadvantage on subsequent work. Mr. Osborn.

In regard to faulty details, that of connecting members together by riveted joints without paying due attention to the proper intersection of gravity lines is probably as common as any. The only excuse for it ordinarily is the saving of a very small amount of material in the gusset plates.

The writer fully agrees with the author regarding the attachment of cross-girders to columns. This connection should be as rigid as practicable, and this can best be accomplished by running the column up to the top of the cross-girder and riveting the two together thoroughly.

It is the opinion of the writer that what is known as carbon primer is superior to linseed oil for a first coat for structural iron or steel. It is thin, flows readily, and unites firmly to the metal. It dries hard and does not give the greasy surface to metal that linseed oil does. It makes a finish to the metal surface that permits the laying out of work as readily as upon the raw material. The carbon primer should be applied as soon as practicable after rolling, and certainly before any tendency to rust appears.

As to the æsthetics of structural steel designing, it is certainly time that engineers gave serious attention to this point. For the ordinary railway structure, architectural appearance is not particularly important, as but few people have occasion to view it. For city or suburban bridges, however, and particularly for elevated railways, the question of appearance is a live one and well worth careful study and consideration by engineers. An engineer as well as an architect owes it to the general public to give a structure satisfactory not only from a utilitarian standpoint, but from an artistic standpoint also. This artistic effect is not necessarily obtained by elaborate ornamentation, in fact too much or inappropriate ornamentation may be worse than none at all. The desired effect may frequently be obtained by a proper and careful study of the principal lines and form of the main structure. A structure may have little or nothing of pure ornamentation and yet be very pleasing to the eye on account of its natural grace and apparent adaptability to the purpose for which designed. Engineers, as a rule, give too little attention to the architectural effect of their structures, and they will doubtless concede that the author has made a distinct and satisfactory advance over what has heretofore been done in this direction by American engineers.

Mr. Pratt. WM. ARTHUR PRATT, M. Am. Soc. C. E.—The writer has had experience only with elevated viaducts designed for the heavy loads of ordinary steam roads. The conditions are different in the case of rapid transit lines in city streets, whether the motive power be electricity or steam, but the traffic is no less constant than in case of the heavier structures. To one who has had to do with the construction and maintenance of these viaducts, several facts are very apparent:

First.—The service is extremely severe, especially on those viaducts forming approaches to important trunk line terminals.

Second.—The deterioration of the structure is much more rapid than in the case of equally well designed work of other types on other parts of the line.

Third.—The foundations require most careful treatment in design and construction, and frequently show settlement, and require more or less extensive repairs before the superstructure develops any weakness.

The writer therefore holds that minimum first cost is not necessarily synonymous with true economy, and that the use of medium steel with high unit stresses, thereby reducing weight and increasing deflections, is a move in the wrong direction. The writer believes from a careful observation of the behavior of many viaducts in actual service that the most durable and satisfactory are those very heavy structures with solid through floors and stone-ballasted roadways. While this latter style of construction is probably not available for a rapid-transit elevated railway built in the streets of a city, the engineer can at least use comparatively low unit stresses, thereby reducing deflections to a minimum and providing additional mass to absorb the impact of the moving load. If low unit stresses are used, there remains no imperative reason for using medium steel, as the ultimate strength and elastic limit of the material are no longer in question; and if soft steel is used, the writer sees no reason for a general reaming specification as his experience shows conclusively that there are several bridge shops in the country which can turn out punched work with an accuracy leaving but little room for criticism.

The author's figures are very seductive, but the writer is by no means convinced thereby that the four-column bent is the best arrangement for a four-track viaduct. The reason for this lack of faith is in what has been previously said about the uncertainty of foundations under viaduct columns. As a case in point the following testimony is submitted. The facts pertain to a viaduct for which the writer provided the superstructure.

Foundation beds, good, compact gravel. Lower course of masonry, concrete 11 ft. square, 3 ft. thick. Balance of foundation, heavy, undressed ashlar in regular courses. Caps, sandstone, 42 ins. square, 20 ins. thick, four anchor bolts in each foundation. Maximum load, 250

tons, of which about 140 tons is live load. Pressure on foundation beds, about 2 tons per square foot. Mr. Pratt.

About 100 of these foundations were built, all of substantially the same character, the beds being apparently of the same good material throughout. After five years' service, 60% of these foundations showed settlements varying from 1 to 3 ins., and of the remainder almost all showed an appreciable settlement.

Additional testimony could be furnished if necessary, but the tenor of it would not differ from the preceding. The writer therefore believes that having determined upon a satisfactory span-length, it is good practice to reduce the number of column foundations to a minimum, using not more than two in a bent, unless other conditions require a modification of this arrangement. This reduces to a minimum the number of points liable to settlement, and the consequent distortion of the structure becomes a less serious question. The liability to settlement of foundations leads the writer to believe also that wherever physical conditions will permit, it is better practice to design the structure with the longitudinal girders carried on the upper flanges of the cross-girders, rather than riveted to the webs of the latter. In case of unequal settlement of adjacent bents, the latter detail would involve severe and possibly destructive strains in the header connections; while but small harm would be done if the track girders were simply seated on top of the cross-girders.

The author believes that a shop coat of boiled linseed oil on finished members is all that is required before erection, and this is also the present practice of the Pennsylvania Railroad Company. Some recent developments in connection with the bridge work of this company have led the writer to believe that this practice is not good. An order of plate girders with $\frac{7}{8}$-in. rivets passed the shop inspection before the oil coat was applied, and the riveting was fully up to the high standard of the shop which furnished the girders. After the delivery of the work and during the erection, the railroad company's men discovered that far too large a percentage of the rivets were loose, and this led to a careful investigation with experimental pieces which were riveted up and tested for loose rivets before and after oiling. The fact was developed that rivets which were tight before oiling could in most cases be readily loosened with an inspector's hammer after the oil had penetrated around the shank of the rivet. The effect of the oil was to soften the scale on the surface of the rivet, at the same time reducing the friction of the rivet heads like any other lubricant. The test pieces were then cut through the center lines of the rivets and showed that the upsetting had been practically perfect. The experiments therefore seemed to show that while many of the rivets would have been condemned by an inspection after the oil was applied, the situation could not have been improved by cutting out and replacing these

Mr. Pratt. rivets. In the writer's judgment the above facts are a possible explanation of the comparatively large number of loose rivets which occasionally appear in certain girder spans that give no indication of poor work during the shop inspection. If the girders were placed in service while the oil was still fresh, they were subjected to substantially the same conditions as were the experimental pieces which were tested after oiling. In the writer's opinion it is better to give the finished pieces a heavy priming coat of some approved paint in the shop than to use linseed oil alone.

Mr. Boller. A. P. BOLLER, M. Am. Soc. C. E.—In discussing a paper like the author's elaborate examination of the problems involved in the construction of elevated railroads, it is impossible within reasonable limits to comment on all the points he takes up. In his sweeping condemnation of all past efforts in this direction, he seems to have forgotten all modern work is a development of the past, and his own excellent work would not have been possible except for the labors of those before him. In the early days of such roads, the science of constructive engineering was only taking shape in this country. The problems involved, as they are now seen, are not complicated, unless one chooses to make them so. The construction is simply a continuous line of girders supported on columns resting on pedestals arranged, as to span and support, according to the local requirements of any given case, and an economical balancing of spans and supports as near as it is practicable to do so, subordinate to the necessities of street traffic. The constructive details necessitated thereby are a matter of the individual taste of the designer, so long as they are controlled by principles of statics and the laws of the strength of materials used, coupled with a full knowledge of shop methods and facilities.

Such structures are not subject to any architectural treatment whatever, and should be built as unobtrusively as possible. The writer prefers plate girder work to lattice work, as it can be made shallower, even at the expense of a little more flange material. For straight-away work, he has always thought the type of the Third Avenue line in New York City, of course detailed with modern ideas, was about the best for a wide avenue, where posts could be put in the avenue, being the least obtrusive. For a narrow street, or where otherwise required, of course there is nothing left but to put columns inside the curb line and girder across the street.

As to pedestals he believes monoliths of well-made concrete are the best, and that the specifications for cement in the paper are eminently sensible, and calculated to produce good results. He is prejudiced possibly in favoring natural stone for cap stones, although the author seems to have obtained satisfactory results with artificial granolithic stone. The author lays great stress on his manner of bolting his

column to the pedestal, but in an ordinary standard pedestal, there is the weight of a comparatively small volume of material above the anchor washers, and were there anywhere near the strain on the bolts he imagines, it would have told long since on some of the pedestals of the New York and Brooklyn roads. This idea of pull on the bolts he has derived from an assumption that 20% of the live load between two adjacent expansion points acts as a horizontal thrust. So far as the writer knows there are no exact data on this subject, but he does not believe it is anywhere near that figure. The rails, guards, etc., are continuous, and distribute what thrust there is over a long distance. The author would ignore this part of the structure as a distributing factor, and go to much trouble and expense to make the structure entirely independent of it. The rails and guards exist, and will do their distributing work, whatever it is, and why ignore them? Many years ago, when the original Greenwich Street line in New York was running, this question came up, and the late Milton Courtwright, M. Am. Soc. C. E., made some experiments as to the effect of braking trains on this, the flimsiest, structure ever built for elevated railway purposes. The writer does not know that these experiments were ever recorded, and doubts if they were made with any scientific refinement, but he remembers Mr. Courtwright telling him that whatever horizontal thrust the brakes produced was so small that it was a matter of no moment, and demanded no special provision. Mr. Boller.

Growing out of this fear of horizonal thrust, the author has evolved a column of heavy cross-section necessitating some complication of detail. His column is a good one, of course, but from magnified assumptions of stress, he has magnified his column beyond necessary requirements. The writer likes his idea of running the columns past the ends of the cross-girders, instead of simply resting the girders on top of the columns, when posts are on sidewalks, also throwing in a strut between longitudinal girders and column head, as well as solid plate-girder corner brackets. These add much to general stiffness, and such structures cannot be too stiff.

The author calls attention to rust conditions around the foot of planted columns, but just how this is to be avoided it is difficult to see. To carry up the capstone above the street surface sufficiently to remove the column above moisture is impracticable in most cases, on account of creating too much obstruction in the streets. His idea of filling the boxed space around the column foot with concrete amounts to little as a protection, as no concrete ever made is impervious to moisture, and it is impracticable to get intimate contact between concrete so placed and the detail of the metalwork. Presumably the only thing that can be done is, before concreting, to plaster the metal surface thoroughly with cement mortar, but even such mor-

Mr. Boller.

tar is only less permeable to moisture than the concrete. This matter is a serious one for all such constructions, and the writer knows of no way of getting rid of the difficulty. The nearest approach to protection is the column planted in a cast-iron pocket, the neck of the casting rising some inches above the plane of the roadway or sidewalk, the voids between columns and casting being well grouted with cement. The greater part of the New York elevated construction is of this character, but coupled with this form of construction is the difficulty or impossibility of getting solid contact between the post-end and the bottom of the cast socket, which cannot be faced. The writer would suggest in any case a thorough priming of the post foot with the best attainable primer, which will not corrode under moisture, and then asphalting with a good natural asphalt. In the darkness and under moisture the volatile oils in such asphalt will probably hold for an indefinite time. Asphalted rails in the tunnel of the Fourth Avenue improvement have lasted well; the same asphalt exposed to sunshine soon becomes powdery and useless.

As to the use of medium steel or soft steel, the writer is an advocate of the former as being perfectly reliable, of higher value and strainable to a higher unit. There is a tendency toward the use of soft steel, encouraged and promoted by the manufacturers, as the supply is abundant, and ease of manipulation in the shop makes it cheaper to work. The engineer is impressed with the arguments of the manufacturer that he is using a safer steel, and one that will better withstand shock. This is all from mercantile interest, for can any steel be subject to higher shocks than rails, connecting rods, driving wheels, etc., all of steel of very much higher carbon than any contemplated for constructive purposes, the very hardness of which gives it value against deformations. Steel must be treated and manipulated according to its quality and grade, and the nearer it approaches homogeneous iron, which so-called soft steel really is, the less expensive is it to work, and the more desirable for the shop.

The author is quite right in all he says about reaming. All first-class riveted work should be reamed, if only for the purpose of truly matching holes, and perfect work can be attained only by reaming through all the parts assembled together. The use of a tapered and flexible reamer should not be allowed, except in some out-of-the-way place that a rigid drill cannot reach, but no prime joint or important connection should be designed so that the rivet holes are inaccessible. A concession for punched holes in soft steel might be made for gussets and secondary connections, but all direct connections, such as webs and flanges, should be reamed in any sort of steel adopted. Metal below $\frac{5}{8}$ to $\frac{3}{4}$ in. in thickness may be sub-punched and reamed; above that thickness, it should be drilled from the solid.

As to the choice between basic and acid steel, in these days there is

Mr. Boller.

not enough difference between them to warrant a preference, except perhaps for eye-bars, where acid steel is the best, for the reason that the annealing of such bars causes such a drop in tensile strength from that shown by the initial steel, that as high a limit of ultimate strength steel should be used as is consistent with toughness and ductility. For this purpose acid steel, made as it is from the best quality of original stock, is the safest and best to use.

The author lays none too great stress on painting, but it does seem almost impossible to have this well done, particularly the vital priming in the shops. The writer does not think much, if anything, would be gained by oiling material in the rolling mill, as the author suggests, for there is much mill scale to come off during shop handling and manipulation, and such oil as remained would interfere with the primer getting in immediate contact with the metal. The best attainable primer should be employed, and it should be properly put on under cover, and dry before shipment. Most work is painted outside with extreme carelessness and shipped fresh, and between the cutting of cinders from the locomotives and the rubbing of pieces against each other, it reaches its destination in a condition no properly primed material should. As good priming is the essence of protecting metal against rust, engineers should exercise more care in the material they use, and see that it is properly put on under proper conditions. If economy is the order of the day, let it be exercised on the outer coatings. Manufacturers are not wholly to blame for sloppy shop painting, as time for completion of work is usually set at such a date that the strain to meet time expectations is intense, to meet which work must be shipped almost as soon as the last rivet is driven, and the shop priming is done on a sort of catch-as-catch-can principle. No work ought to be crowded quicker than it can be done rightly, and engineers, in so far as they can control, should see to it that the time exacted can be properly met.

The author's account of his letting, at which certain manufacturers tendered on other conditions than those asked for by the specifications gives an exhibition of practices entirely too common. In public works, the law compels the throwing out of such tenders as irregular, and it ought to be done in private lettings. It is eminently unfair to other bidders, and derogatory to the right relation between the engineer and contractor. It is highly impertinent in a manufacturer, when asked to tender under a certain specification, to ignore the requirements of the same, by bidding on a basis that better suits his own shop facilities, hoping to go over the engineer's head by attracting the buyer with a lower price. No self-respecting engineer should permit such an effort to succeed, and it is refreshing to see that the author stamped it out in his case. In making these remarks the writer does not wish to be understood as belittling the knowledge and

Mr. Boller. experiences of the shops, for much of the marvelous advance in constructive engineering is due to them, fully as much, if not more, than has been contributed by the purely professional brethren. But the wise engineer will familiarize himself with shop facilities and experiences in details and methods of construction, which every shop accumulates in the course of a business career in contact with many minds, out of which he will edit, as it were, the best practice for his own particular work. The writer has not much respect for the engineer who tries to evolve everything from his own inner consciousness, oblivious of the many bright minds that have added to the wealth of experience and possibilities. The author has shown great familiarity with the best shop practices and modern ideas of designing, and he has gleaned well from past experience with an enviable industry that became crystallized in such an elevated railroad as he wanted to build. In the face of this, to have a contractor asked to bid upon that construction of road come forward and turn the engineer's plans down, endeavoring to substitute some of his own, for purely commercial reasons, advanced under cover of more or less technical speciousness, was a very high-handed proceeding. It is certainly a satisfaction to know that the parties fell into the pit which they dug for others. In this connection the writer wishes to remark that after a work is awarded, it is perfectly proper to favor the successful shop by such modification of details as may best suit the special facilities and conveniences of that shop, without sacrificing any general principles. An arbitrary adherence to a notion is not good business or sensible engineering.

The author concludes his paper with some remarks on the æsthetics of designing, with an architecturally treated road as he would like to build one. It is sincerely hoped he will not have the opportunity, for if the elementary principle of sound architecture "not to construct decoration but decorate construction" can be violated, it has been certainly accomplished in the design submitted. There is a homely old expression, that "you cannot make a silk purse out of a sow's ear," which fits here, for you cannot make an architectural (æsthetic) structure out of an elevated railroad, despite false arches, foliated column caps, or gargoyles on the ends of the brackets.

Mr. Stuart. A. A. STUART, M. Am. Soc. C. E.—While the writer desires to go on record as approving most of the conclusions reached by the author in evolving the various details of construction described in the paper, yet there are some statements made and details employed which he feels are neither founded upon facts nor sustained by experience. The initial statement that methods heretofore employed in designing structures for elevated railways are radically wrong is rather too sweeping to be sustained by facts, nor is it justified by a careful examination of the designs presented by the author, since they do not differ

in essential elements from recent designs employed in other cities where the limiting conditions were at all similar. There are differences in some of the details, but the relative merits of these are the subject for debate rather than the hasty judgment that any one is superior to all others. Such differences doubtless will always exist, and can well do so without subjecting any particular one to the charge of being radically wrong. The structure in Chicago chiefly treated by the author, being located on property owned or controlled by the railway company, made it possible to employ the braced-tower construction, which has never been applicable to the structures in either New York or Brooklyn, because they are located wholly in public streets. This feature constitutes the only radical difference between the author's design and the design of the structures built in New York or Brooklyn within the past few years, but its absence in the latter certainly does not warrant the statement or belief that their design is radically wrong. Mr. Stuart.

As to the desirability of having all rivet holes precisely concentric in members to be united, there can be no question raised, but the writer's observation does not lead to the belief that the expense which would be entailed in securing this by the method suggested by the author would be justified. The use of riveted work in this country has been very extensive and covers a long period, but so far as the writer has been enabled to learn, the present methods of manufacture employed by the best shops have given satisfactory results under a large variation in service; hence any change in those methods involving so much additional expense does not appear to be warranted.

In the matter of Portland cement, the author's specifications are gravely inconsistent in that he exacts the best possible quality obtainable, while in the next paragraph a physical requirement is stated which the poorest cement in the market would fully satisfy. Indeed the wide latitude permitted in the tensile strength is of itself generally regarded as unfailing evidence of poor quality. The writer makes special reference to this here in the hope that it may at least serve in a small degree to eliminate such inconsistencies or ambiguous expressions from specifications, believing that they are the most fruitful source of contentions and disputes between engineer and contractor.

As to the track system presented by the author, it is almost identical with that used on the older roads in New York and Brooklyn, which has been much modified as a result of long experience on those roads. The writer has never been able to conceive of any adequate reason for using inner guard rails on straight track, but, on the other hand, will state what he believes to be several rational ones for omitting them. While it is possible for a derailment to occur on an unobstructed piece of straight elevated railway track, it is a very remote

Mr. Stuart. possibility when gauged by the fact that an experience of twenty-five years on the New York elevated railways furnishes no instance of such an occurrence. This fact alone would seem to deny the utility of these guards in averting calamity, the only purpose for which they are employed. Should a derailment occur, the question arises whether the outer guard rail does not offer ample security, if left to act alone, in preventing a truck from leaving the structure.

This is certainly true if the four guard rails are spaced, as in the author's design, so as to require each to act independently instead of in pairs. If inner guards are used at all, they should be so spaced that opposite wheels of a derailed truck would encounter an inner guard and the opposite outer one at the same instant, and neither guard should be laid so near the track rail as to prevent a derailed wheel from dropping into the space, except, of course, on curves. If the inner guards are never called upon to perform any service, then their use is not justified, and they should be omitted for the reason that they add additional perishable material to be removed, and otherwise increase the cost of track maintenance by shutting out air and sunlight from the ties, thus hastening their decay, and they add much difficulty in making repairs to track rails and ties. It is a matter of much surprise to see the use of short hook bolts revived by the author, in view of the evident advantages possessed by the long hook bolt, which engages the flange of girder, tie and outer guard rail in one mechanical operation.

Referring to the use of treated timber in the track system, the author's conclusions, not being based upon facts developed by experience, are very misleading. It is not true that yellow pine or any other timber used for structural purposes becomes unfit for further service after 7½ years' use in elevated railway tracks, or even in surface tracks. A very large percentage of the timber laid in elevated railway tracks 12 or 15 years ago is still in service, and will so remain a number of years. The writer believes it to be a safe assertion that its average life is quite 15 years in such a situation, if not destroyed by mechanical means, assuming that reasonable care and judgment are employed in its selection. The largest number of renewals made within the first 10 or 12 years are rendered necessary by mechanical agents and not chemical ones. While it is true that the cost of labor for renewing a single tie averages about $1, it is not a fact that the largest percentage of timber would be renewed in this way, but in continuous sections, where the circumstances would reduce the cost of labor to a sum not much in excess of that required for laying new track. These facts would materially alter the author's conclusions if incorporated in his computations to ascertain the relative merits of treated and untreated timber.

From a theoretical standpoint, the author's criticism of the neglect

to proportion all columns for resisting flexure is fully justified, but the writer has satisfied himself by careful observation that the assumptions usually made as to the magnitude of stresses which the columns will be called upon to resist are very much in error, else few or none of the structures in New York or Brooklyn would be standing at the present time. These structures themselves afford the best and most reliable evidence of their ability to resist safely both longitudinal and transverse stresses which are brought into the columns, and a careful observation of their behavior under conditions producing maximum stresses will fail to disclose any evidence whatever that they are excessively strained. The writer has seen and very carefully noted the conditions where the transverse girders were cut entirely loose from the columns over a distance of nearly a quarter of a mile, the structure being supported temporarily on 15-in. square timbers clamped to the remaining stubs of the iron columns, and while in this condition a three-minute interval train service was maintained over the structure, which is on a 2% grade, without producing any increased vibrations so far as could be detected.* It seems to the writer that, in addition to other interesting features involved in this work, it furnishes confirmatory evidence of a very pronounced character that the customary assumptions relative to lateral stresses in such structures are not substantiated by facts, and it is believed that much metal has been wasted in providing for stresses which appear to exist only in the imagination. Mr. Stuart.

The cement finish used by the author to cap the concrete foundations has given very satisfactory results on Brooklyn roads during the past four years, but the writer does not believe that a mixture of one part cement to three parts of crushed granite, as described by the author, will give satisfaction, either in the matter of finish or durability, since it is too porous to admit of good troweling and prevent disintegration by frost. Indeed, this mixture is no richer in cement than the concrete used in the body of the work below the frost line, where it is protected from abrasion and the unit pressure is very much less than immediately under the columns.

ALBERT A. TROCON, M. Am. Soc. C. E.—The author says that "there is no bridge shop in existence which can turn out truly first-class work without sub-punching and reaming or drilling." The writer thinks there are a great many shops that can do so, or rather that all of them worthy of the name can, if the proper care is taken. The care required to do this is much less trouble than that caused by having to sub-punch and ream. The writer knows that in the shop with which he is connected, the punching is usually done so accurately that very little or practically no drifting is required. When the holes did not match, it was generally found to be the fault of the laying off, Mr. Trocon.

* See *Transactions*, Vol. xxxii, p. 363.

Mr. Trocon. and in these cases reaming would have been of no avail, as the holes were too far apart to be remedied in that manner.

The idea that rivets cannot be driven so as to fill the holes completely when the latter are punched only, and they are left of slightly varying diameters, seems to the writer erroneous, especially where the rivets are machine driven, which is the universal method in bridge and structural work, except in the few places where they cannot be reached by a riveter. He has quite often seen specimens of riveted work, with holes punched only and not reamed, sawed through the center of the rivets, where they so completely filled the holes that it was difficult to distinguish the lines separating the rivets from the balance of the material. Some of these specimens contained five or six plates riveted together. The writer thinks that most manufacturers will concur in his views. If it is the case, then, that holes can be made to match so perfectly by punching without reaming that there will be no trouble in making the rivets enter into their places, what is the use of requiring manufacturers to sub-punch and ream (when punching alone does not injure the material), thereby causing an extra expense of from 0.1 to 0.25 cent per pound? The writer thinks it good practice to ream holes for field connections, as this facilitates erection, but not otherwise, unless in steel so hard that there is danger of cracking the material in punching. He is not so sure, however, that this is required, even for medium steel, and certainly not for soft steel. The fact that most manufacturers do not like to ream work, as acknowledged by the author, goes to show that they do not think it necessary, and that they can do good work without it, as they otherwise would certainly rather ream their work and get paid extra for it than punch it unevenly and have to drift excessively, which would cost them almost as much as reaming, and for which they would not be paid.

Another point the writer does not believe in is that "every column ought to be anchored so firmly to the pedestal that failure by overturning or rupture would not occur in the neighborhood of the foot, if the bent were tested to destruction." He does not believe in it because it is impossible to accomplish it without a great deal of extra expense, and in some cases it is impossible any way. All columns should be well anchored, so well as to resist all shear coming against their bottoms and to resist tension if there is any. He thinks it preferable to treat the column as free at the bottom and increase the section in figuring for bending effects of longitudinal and transverse thrusts than to treat it as fixed and attempt to build it as such. It is doubtful whether the cost would be any more that way, in most cases, than with the anchors proposed in the paper, and the column cannot really be made continuous except by running it down and imbedding it in the concrete for a considerable distance, which would be very expensive and in many cases an impossibility. Again, there are cases where

the columns have no bending to take care of, when it would manifestly be a waste of money to anchor them so as to make them continuous. Mr. Trocon.

WM. BARCLAY PARSONS, M. Am. Soc. C. E.—An elevated railroad, if built along a street, should be designed primarily from the point of view of the users of the street and not from the point of view of the railroad. A street is not a proper place for fast-running, power-driven railways. Such railways can be better built for their own uses on right of way to be acquired for the purpose, and when so built can be more satisfactorily operated. If for any reasons it is necessary to use a street, and the abutting owners and the users of the street surface are made to suffer *pro bono publico*, the greatest consideration in the design should be shown for their convenience. Mr. Parsons.

A design for an elevated railroad, apart from meeting the requirements of a bridge structure, as laid down by the author in his points *F* to *O*, under the head of designing, should conform to the following general requirements:

First.—It should occupy as little of the street as possible.

Second.—Its columns should be placed so as not to interfere with vehicular traffic.

Third.—It should give the minimum obstruction to the passage of light.

Fourth.—It should be noiseless, or as near as it can be, to the passage of trains.

Fifth.—The tracks should be placed preferably over the center of the street and not over the sidewalks, so that the drip in wet weather will fall upon the tops of vehicles rather than upon pedestrians.

Sixth.—The structure should be inoffensive to the eye.

Strict economy in the design should be the last point to be considered, and therefore the spacing of the girders, both longitudinally and laterally, should be made to conform to local requirements. In order not to interfere with street travel, longitudinal and cross bracing between the columns, except at a clear height of 12 ft. above the surface of the street, is not possible. The ordinary heights, such as are to be found in elevated railroads, preclude any such bracing, and therefore, the only stiffening that can be given either longitudinally or laterally is by means of corner brackets. The author points out very carefully the necessity for both longitudinal and lateral stiffness, and states that all elevated railroads as at present designed are merely examples of what not to do. Had he gone into a criticism of these awful examples, he would probably have mentioned their lack of stiffness as one of their chief defects.

The writer some years ago had occasion to investigate personally the movement of New York elevated railroads under passing trains, which he did by means of a transit. He was surprised to find that on

Mr. Parsons. curves there was no movement perceptible beyond vibrations. This, however, was not the case with respect to longitudinal movement. At points near stations when the approaching trains applied brakes, the whole structure would move forward perceptibly. The instant that the brakes were released, although the train might still be in motion, the structure would go back beyond its original position and then move forward beyond the vertical hair of the transit, and back again before coming to rest.

Of the various designs submitted by the author for two-track structures, the writer prefers No. 8, where the outer stringers are in line with the columns. The objection urged by the author to this design

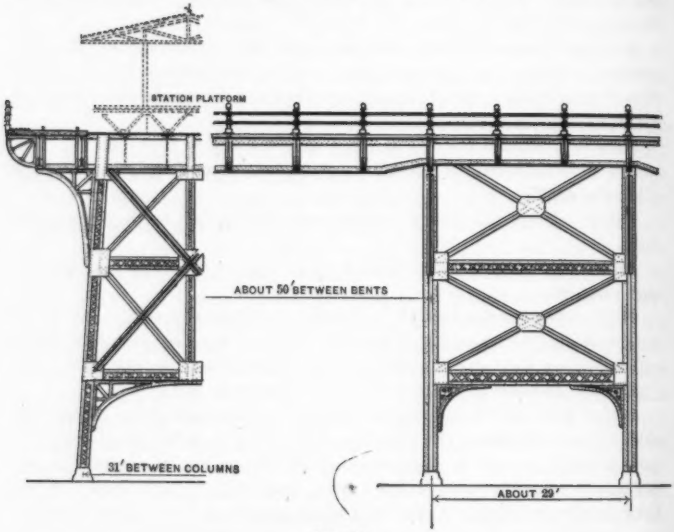

FIG. 33.

in regard to the bending of the cross-girders appears to the writer to be slight. Unless a column can be placed directly beneath the track, with stringers balanced about it, one stringer or the other will periodically be depressed slightly more than its mate. There is the advantage, however, of making at least one good connection, and of being able to introduce longitudinal brackets, which, like portal braces, can take up strain or movement.

The plans which the writer has prepared for the Rapid Transit Commission of New York include two designs for elevated railroads, one a high one across what is known as Manhattan valley, 2 800 ft. in length, and the other an ordinary structure. These designs are shown

in Figs. 33 and 34. In the high one provision is to be made for four tracks eventually, but only the two outer ones to be constructed immediately. The intertrack space is to be utilized for island platforms. On account of the height, 55 ft., the structure in side elevation has been divided into alternating long and short spans with the towers rigidly braced. The design for the lower structure follows the general lines of the author's Design 8, lateral and longitudinal stiffness being supplied by the curved brackets. Mr. Parsons.

The author speaks of making elevated railroads pleasing to the sight. That is an exceedingly difficult matter, if not impossible, unless the straight lines of utilitarianism aided by the details of good

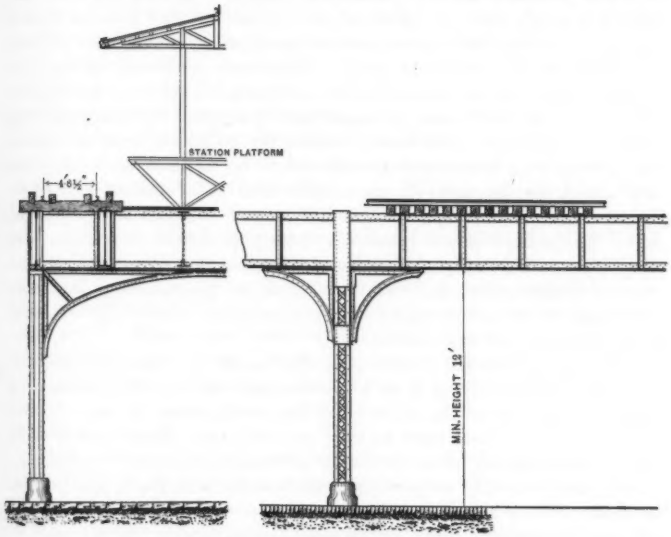

FIG. 34.

workmanship, can add beauty. Any built-up ornamentation, as in the æsthetic designs submitted by the author, will tend to still more darken and injure the street, and therefore by doing harm cannot be beautiful. It is to be remembered that true ornamentation should conform to, or suggest, the purpose of the whole, and the designs proposed by the author, while furnishing perhaps a pretty passageway to a ball room, do not in their details, especially in the loose and festooned hand rail, seem to the writer as in keeping with a railway. The author has, however, done a good thing in calling attention to the needless ugliness of most of our structures. That possibly the simp-

Mr. Parsons. lest details are the best is exemplified in the Stadtbahn in Berlin, where the Germans, although lavishly ornate in most of the design, were much restrained in treating the metal elevated way. The columns are small, so as not to take up space, and of cast or wrought iron. In either case the decorations are in keeping with the metal. The supporting stringers are usually a plate girder construction, and paneled between the stiffeners. The details of construction show care in execution and design. The side walls are bracketed out and so cast a deep shadow. The whole is pleasing to the eye.

Mr. Greiner. J. E. GREINER, M. Am. Soc. C. E.—The design of an engineering structure necessarily admits of a variety of means to accomplish the purpose intended, and the personal selection of any particular means does not imply that the preference is positively the best, or that a modification or different arrangement proposed by some other individual could not be equally as good. Therefore, while the author has pointed out what he considers the best cement, paint, span-lengths, dimensions of track rails, arrangement of wooden floor, material for pedestal caps, style of anchors, sections for columns, style of expansion joints, etc., the selections made are to be understood as only the best which his judgment dictates, and not as yet definitely settled by either common concurrence or the ballot box. As this is a matter of individual judgment and opinion, a discussion would be useless; but the writer would really like to know why one coat of linseed oil, one coat of Eureka paint, and one coat of oxide paint, all on the same structure, are considered the best metal paints to adopt. There must be some reason for this variety.

The question raised concerning the use of the basic process for steel of a medium grade is an important one, as it is the tendency of the mills throughout the country, at the present time, to make just as little acid open-hearth steel as they possibly can. Basic open-hearth metal, when over 60 000 or 61 000 lbs. ultimate, is not so uniform in quality and probably not so trustworthy as the acid steel, which must be made from a superior grade of ore, and the mills would always prefer to furnish the basic, which can be charged with cheap ores.

There is also a tendency at the present time among the different bridge shops, even those of the highest standing, to under-rate the value of reaming and drilling a medium grade of steel. Of course all can understand that the object of the bridge shop is to manufacture a bridge just as cheaply as it can be done to the satisfaction of the buyer. If it can induce the buyer to avoid reaming or drilling, or planing sheared edges, it can complete its work at a somewhat less cost. It should not be censured when some of the most recent specifications allow this grade of steel to be used in the most important bridge structures at a higher unit stress than usual for soft steel, without requiring a better class of work. Personally the writer can see no reason

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why a higher unit stress should be allowed for medium steel than for a soft steel, if both grades are to be subjected to precisely the same treatment in the shops. If higher stresses be allowed for medium steel, then something more is required than merely an increased ultimate strength and an increased elastic limit, and any specifications which increase the unit stress for a medium steel, without at the same time providing for the necessary precautions to insure accurate workmanship and removal of incipient cracks, are taking a stand, which, while probably sanctioned by the manufacturers whose interest it is to cheapen work, should not meet with the approval of engineers who count on every square inch of section in their structures as available material undamaged by shop manipulation. Soft steel, that is, steel between 52 000 and 60 000 lbs., can be treated just the same as iron up to a certain thickness was treated. This is generally admitted. The metal flows easily, it is not liable to crack and will stand an immense amount of abuse, and if the shop punching is fairly well done and all important field connections matched in the shop and reamed, there is no doubt but that the result will be a first-class structure.

What argument can be advanced which will justify the use of a harder metal at a higher unit stress than allowed for soft steel when this harder material has nothing in its favor except a little higher ultimate and a little higher elastic limit? It is inferior in ductility, it is more apt to be brittle, it will not stand the same amount of drifting, bending or other abuse usually required for soft steel, and it is injured to a greater extent than soft steel by punching and other rough shop work. When using a harder steel with a higher unit stress engineers should insist upon treatment and workmanship which will minimize abuse, and, as the author states, there is no bridge shop in existence which can turn out thoroughly first-class work without reaming or drilling.

The probability of increased train-loads in the future, and an occasional blow from derailment, and the continual vibration due to fast speed, all have a tendency to develop flaws or defects invited by rough workmanship. This development may not take place to-day or to-morrow, but who can say that it will not occur the day after? Precautions taken in the interest of safety should not be sacrificed for the sake of a very small fraction of a cent per pound.

In this connection the writer desires to state that, while at the present time he is using both soft and medium steel, the former treated same as iron and worked with a low unit stress, the latter reamed or drilled and a higher unit stress used, he believes that should he have occasion to renew his 1896 specifications, he would specify but one grade of steel, having 60 000 lbs. ultimate with a variation of 5 000 lbs. more or less. He would use soft steel unit stresses for ordinary bridges, and work the steel without drilling or reaming except in im-

Mr. Greiner. portant connections. For bridges having spans of 250 ft. or more, he would use higher unit stresses, and ream or drill all holes, and would consider that the benefit derived from the more accurate workmanship would justify the increased unit stresses for precisely the same grade of material.

Mr. Belknap. W. E. BELKNAP, Assoc. M. Am. Soc. C. E.—Taking up Section 3 of the paper, which is headed "The Best and Cheapest Kind of Portland Cement to Adopt, and the Best Proportions for Concrete made with Same," it will be found that in the specifications for the "best quality obtainable" of Portland cement, the requirements for neat tensile strength for twenty-eight days are 400 lbs. per square inch. The specifications read, "from 400 to 600 lbs.," but the minimum limitation alone carries weight. The writer ventures to assert that there are quite a number of high-class domestic Portlands that will run, not only above 400, but far above 600 lbs. on a 28-day test, and that it would be the common opinion among engineers that such cements would be much better than a 400-lb. cement. The same criticism is applicable to the requirements for sand briquettes. The writer has no intention of suggesting the requirements for "best" Portland cement, but is of the opinion that while the author's recommendations might secure the cheapest, they certainly do not assure the best.

The value of stating a requirement which ranges between limits from 50 to 150% of the minimum apart is difficult to discern. Specifications should as much as possible avoid compelling verbal explanation. If the engineer's minimum limit for a certain quality is fixed in his own mind, he should state it explicitly and adhere to it. A dealer supplying 600-lb. cement does not ordinarily place himself in competition with a 400-lb. article; and it is quite apparent that under the last clause of these specifications, to secure the chief engineer's approval of his own brand as a "best" cement with any meaning, he must also secure the disapproval of 400-lb. brands. These are specifications which do not specify.

With respect to the author's suggestions concerning concrete for pedestals, the writer is of the opinion that with either graded or uniform-size stone, the voids of the same can be filled with mortar in a one-three-six mixture, and that this is more dependent on the manipulation and subsequent consolidation of the concrete in place than on grading the stone very carefully and thoroughly mixing the various sizes, each of which precautions would probably cost considerable, were they literally carried out as the author suggests.

Mr. W. M. Patton, in his "Civil Engineering," gives the voids in concrete stone as follows:

Uniform size—2½-in. ring	37.07%
" " 2 " "	39.50%
" " 1½ " "	42.00%

Mr. A. W. Dow, in the "Report of Engineer Commissioner of District of Columbia, for 1896," gives the voids as follows: Mr. Belknap.

Average concrete bluestone	45.3%
Coarse concrete stone	45.3%
Mixture of 1 part average concrete stone, 1 part small gravel	35.5%
Mixture of 2 parts average concrete stone, 1 part small gravel	36.7%
Mixture of 3 parts average concrete stone, 1 part granolithic bluestone	39.5%
Gravel, "average gravel"	29.3%

William M. Black, M. Am. Soc. C. E., in "United States Public Works," gives the voids in screened and washed, piled loose, concrete stone passing a 2-in. ring, as 46.5 per cent. The writer has found the voids in washed gravel of mixed sizes running from $2\frac{1}{2}$ to $\frac{1}{4}$ in. to be 41.0 per cent.

It will be noted that in none of these cases do the voids amount to 50 per cent. Theoretically, therefore, in a one-three-six mixture the mortar would be in excess of the amount required to fill the voids. In the relation of mortar to stone this mixture is almost practically the same as a one-two-four mixture, with which the writer has experienced no difficulty in the matter of filling the voids without taking either of the precautions referred to.

While it apparently stands so in the paper, the writer does not believe that the author recommends an "eminently slow-setting cement" for concrete to be deposited under water.

A combination of Sections 5 and 12 of the paper leads the reader to infer that the only timber used was "vulcanized" long-leaf yellow pine passing "clear" inspection. It is difficult to conceive that a railroad company would countenance the gross extravagance of using the most costly grade of timber when the preservative treatment of cheaper grades would give an article much more economical. The claims of economy set forth by the various preservative companies are based in a large part on the probability of making the inferior grades of timber more durable than the higher grades. In relation to "Vulcanizing," it may be pertinent to quote from a publication* of the Division of Forestry, Department of Agriculture. In this process it is claimed that "the chemical condition of the sap may be changed into a preservative composition" by heating the timbers to "from 300° to 500° Fahr. under air pressure of 100 to 175 lbs. per square inch"; or "by substituting a vacuum for the pressure and a low temperature to effect the same result, namely, to 'vulcanize' the wood. There is no knowledge of the physiology or character of wood to sustain the

* "Bulletin No. 9, 1894," p. 243.

Mr. Belknap. claim of the physical change, nor has the material been long enough on trial to prove by experience the value of the process. Tests of treated and untreated material of such nature as to make the material comparable otherwise, made by the Forestry Division, did not show any increase in strength, as claimed, nor any chemical or physical changes."

In view of this statement of the Forestry Division, which must be given considerable authority in such matters, such data and tests as the author may have contradictory to the preceding would be not only interesting but very valuable, particularly as his figures demonstrate a large economy on the assumption of the process being efficient.

Mr. Cowles. W. L. COWLES, M. Am. Soc. C. E.—The paper is a valuable contribution to the literature on this subject, and is especially commendable in calling attention to the defects in existing structures, and in laying down the broad principle that an elevated railroad should be equal in all respects to the best class of railroad bridges. It would seem that this proposition should need no argument, for, as the author says, the service of the structure is much more constant than that of most railroad bridges, and the maximum load effect is more frequently reached, while the successive starting and stopping, with the attendant longitudinal thrust caused by the braking, calls for special rigidity in its design and the best of shop work in its execution. Surely any accident which might occur through faulty design or construction would not be attended with less serious results than a similar accident to a railroad bridge, while the possibilities of disaster as affecting adjoining property and loss of life in streets, through a collapse of an elevated structure, furnish additional reason for thoroughness.

The selection of material made by the author was doubtless in accordance with the results of his careful investigation, and seems to have been determined upon as giving the most economical construction upon the basis of universal reaming. There is probably little question as to the benefit accruing from re aming all holes in medium steel for the purpose of insuring solid metal around the holes, but the writer is not yet prepared to accept the statement made by the author that all material should be so treated. The author is quite correct in holding that even in the best shops it is impracticable to punch holes to match perfectly, and there is certainly advantage in the riveting if the component parts of members are so assembled that all rivets will enter the holes freely, but this object can be attained by the use of the tapered flexible reamer to which he refers. This he admits, but contends that in such holes the rivets will not completely fill out, and will therefore not act effectively. The writer understands that reference is made to long members, such as chords and posts of a bridge or columns of a building, and, as applied to such members, which constitute a large proportion of the work of most shops, he does not

accept the force of the argument. The effective action of rivets in the body of such members does not depend upon the complete filling of the holes so much as upon the formation of full heads, well closed down upon the surface of the steel, since the office of the rivet is not to transmit shear, but to hold the component parts of the members tightly together, so that the strength of the unsupported portions of any part may in no case be less than the strength of the member as a whole. The rivets in reinforce or pin plates, in brackets on columns, in the ends of the flanges of girders, and in all positions where the full efficiency of the rivets in shear is required, should completely fill the holes, but such rivets ordinarily occur only in comparatively small small portions of a member, and the component parts can generally be so adjusted that these holes will come fair, leaving what mismatching there may be to come in a part of the member where the rivets are not in shear, and where the flexible reamer will accomplish all that is necessary. Mr. Cowles.

The writer is in favor of reaming all holes for field connections, especially where the number of holes is large or the connection complicated, and does not intend to argue for poor workmanship or careless punching, but is of the opinion that while there may be a satisfaction in the consciousness that work is nicely done, the extra expense involved in the sub-punching and reaming of all holes in soft steel and iron is not commercially justified by any benefit derived therefrom. He does not believe that metal work constructed of such material, carefully punched and assembled and well riveted, can properly be excluded from the term "first-class work."

A. C. CUNNINGHAM, M. Am. Soc. C. E.—Within the recollection of most members, when an engineer desired to build a structure of steel, it was only necessary for him to specify "steel" of certain physical properties. That he would obtain the product of the Bessemer converter was assured, for there was, at first, no choice or alternative. Some of these first specifications are in use to-day with few or no changes of importance, though far better steel is furnished under them than they were originally intended to cover, owing to improvements in manufacture and increased knowledge. Mr. Cunningham.

Some of this early Bessemer steel, high in phosphorus and sulphur, overdosed with manganese, and filled with oxide of iron, would to-day be branded as a villainous mess. Of the structures made of this steel, many have been taken down, some have fallen down, and the balance will come down in some way in the course of time.

Engineers who were using steel presently had their attention called to another process than the Bessemer by which a better and more desirable product could be made, and which, by the time it reached the structural engineer, had become generally known as open-hearth steel. Where the best results were of more importance than the actual cost,

Mr. Cunningham.

open-hearth steel was now specified, and those whom necessity still compelled to use Bessemer steel made their specifications to read Bessemer or open-hearth steel, with little or no hope of getting the latter.

The deadly enemies of iron and steel have always been and always will be phosphorus and sulphur. Owing to the much greater cost of manufacture of the early open-hearth steel over Bessemer steel, a much better melting stock, lower in phosphorus and sulphur, could be used for the former without much increasing its cost, and to this superior melting stock was largely due the superiority of the open-hearth steel.

The superiority of open-hearth steel to Bessemer being partly due to improved methods which largely increased its cost, and partly due to the use of a better stock which did not much increase its cost, manufacturers of open-hearth steel at once called attention to this superiority of composition in advocating their product. Recognizing both advantages, the engineer who could not avail himself of the first took advantage of the second and began to put limits on the dangerous elements in Bessemer steel, rightly inferring that what would improve the one kind would improve the other. These first chemical limits for structural steel were quite generally confined to phosphorus.

Having discovered that phosphorus and sulphur could be neither utilized nor neutralized to any extent in steel, the steel-maker next turned his attention to eliminating these troublesome elements, with the happy result of developing the basic process of steel making. The mechanical differences between the basic and the older processes are slight, the chemical differences are great. Being made in the same kinds of furnaces and converters as the older steels this new product needed only a qualification to have a name, and was quite naturally called basic Bessemer and basic open-hearth steel.

The acceptance of these terms made at once a family name of Bessemer and open-hearth, and the originals were christened acid Bessemer and acid open-hearth. Specifications reading Bessemer steel or open-hearth steel were no longer definite, since Bessemer and open-hearth steels could each be made by either the acid or basic process.

The original open-hearth steel, now called acid open hearth, is made by a comparatively simple process. The hearth of the furnace is lined with silica, whence the name acid, and on this is placed the melting stock, consisting of pig iron, iron or steel scrap and iron ore. This charge is melted down, the silicon and manganese burn out first, and then the carbon to the point desired by the steel-maker, when the furnace work is complete. If the phosphorus and sulphur burned out also, the basic process would never have been heard of, but unfortunately they do not. Whatever amount of phosphorus and

sulphur was in the original charge remains in the steel. From this the reason for the well-known uniformity of acid open-hearth steel may be seen. The phosphorus and sulphur can be exactly estimated from the original charge. The steel-maker has only to give his attention to the reduction of the carbon to the desired point, and when he has made his manganese additions, the steel is finished. Unless chemical limitations are placed upon the dangerous elements, acid open-hearth steel may be uniformly bad, instead of uniformly good. Mr. Cunningham.

In the basic open-hearth process the hearth is lined with dolomite. In addition to the pig, scrap and ore, the charge contains lime. From the dolomite lining and the lime in the charge comes the name basic. The object of the lime in the charge is to unite with the phosphorus and sulphur, and pass them into the slag. Were lime charged into an acid furnace, it would act on the silica lining in preference to the phosphorus, but in the basic furnace it has no action on the dolomite. The greatest action of the lime in a basic charge is on the phosphorus; its action on the sulphur is much less.

The basic process being essentially a dephosphorizing one, it is possible to use for it a melting stock so high in phosphorus that steel made from the same stock by an acid process would be worthless. The regulation of the carbon becomes therefore of secondary importance to the reduction of the phosphorus to at least a safe limit, and as the carbon may be nearly all eliminated before the phosphorus is reduced, it becomes necessary in most cases to make carbon additions. It is not essential to the success of the process that the phosphorus in a basic open-hearth charge should be large; it may be as low or lower than in a charge for good acid steel, in which case the phosphorus will be nearly all eliminated.

The irregularities of basic open-hearth steel may be best illustrated by assuming a specification, and then seeing what may happen under it. As sometimes happens a specification originally intended for acid steel is applied to basic without change, and as this will give an extreme case, such a one will be taken; ultimate strength, 60 000 to 70 000 lbs. per square inch, phosphorus not to exceed 0.08 per cent.

A cast containing 0.08% phosphorus would require 0.12% carbon to give 60 000 lbs. in ordinary sections, and a cast containing only a trace of phosphorus would require 0.3% to give it 70 000 lbs. under the same conditions. By skilful treatment both these casts may be made to pass the same specification, though they are at the extreme limits. Now, under varying conditions, these two casts will give very different results. The 0.3% carbon cast will be found much more sensitive to heat treatment than the other, and can be hardened to a much greater extent, and correspondingly softened on annealing.

Mr. Cunningham.

Specifications for basic open-hearth steel seldom allow the phosphorus to exceed 0.04% or 0.05%, but they never prevent it from going to a trace, which frequently happens, and if the allowed variation in ultimate is, say, 56 000 to 64 000 lbs., steel having from 0.12% to 0.24% carbon may be found under such a specification.

Such variations as this are not likely to be found in acid open-hearth steel, for, if the phosphorus limit is 0.08%, the steel-maker will not go much below this on account of the increased cost of the raw material. With basic open-hearth, however, the difference in cost between 0.04% and a trace of phosphorus is only the difference of the slight excess of lime required to produce it.

Basic open-hearth steel is naturally a soft material on account of the low point to which the carbon is reduced in the furnace, and if a high ultimate is desired, it must be reached by adding carbon to the steel at the end of the process. Such carbon additions are made by throwing coke into the ladle into which the steel is tapped, and, as this does not always become thoroughly mixed with the steel, some parts are sometimes found to be harder than others.

From the foregoing it may be inferred that several heats of basic open-hearth steel may fill a specification, be of excellent quality, and at the same time of variable composition. Unless sulphur is limited in a specification for basic open-hearth steel, it is possible to get a product which is high in this dangerous element, for it is not reduced to the same extent by the process as the phosphorus.

There are advantages in connection with the basic open hearth which are of great importance, and the principal ones are the possibility of producing a very low phosphorus steel and a very soft and ductile one at a moderate price.

The low phosphorus scrap resulting from the basic process, however, at once permits of a low phosphorus acid steel at a competing price, and when strong steels are wanted, they can be made with more regularity and certainty by the acid process than by the basic, for they do not depend on carbon additions to the same extent, and are, therefore, freer from the possibility of uneven mixing.

When it is desired to make a specification to cover both acid and basic open-hearth steel, it is well to make separate provisions for the chemical limitations at least. For acid steel a limit of 0.08% of phosphorus and 0.06% of sulphur, and for basic steel a limit of 0.04% of phosphorus and 0.05% of sulphur will produce good results and admit of competition between the two steels.

A range in ultimate strength between 56 000 and 64 000 lbs. will cover both steels to advantage. For basic open-hearth alone, 52 000 to 60 000 lbs. will give excellent results, while for acid open-hearth 60 000 to 68 000 lbs. will be found quite uniform and reliable.

C. E. Fowler, Assoc. M. Am. Soc. C. E.—The attention paid to the details of the work, as evinced by the paper, is certainly commendable. Very few realize, however, as can the bridge companies which are doing work under many different engineers, what a great variety of details are considered best. One point that has impressed the writer on most recent work is the tendency to err on the safe side, if such can be called error. Mr. Fowler.

After working under specifications of many of the trunk lines and of many consulting engineers, the writer has adopted in his own specifications soft medium steel, from 55 000 to 65 000 lbs. ultimate, as being the metal that will undergo the manufacturing processes with least liability to damage, and avoid the necessity for reaming.

As most shops get out work at the present time, making a wood templet for each piece in a structure, it can only be extreme carelessness if holes in assembled members do not match well, and it is usual to see the holes match perfectly in girder flanges for the entire length. Compressed air reamers are used in most shops on all work to clean out the burrs and true up holes, thus avoiding the cause of drifting, and saving delay and expense in shop work. It is not usual to use reamers of such great taper as the paper seems to suppose, and practically true holes result. For reamed work where $\frac{3}{16}$ in. is to be removed, twist drills are used, and with experienced workmen work is done which cannot be distinguished from that of fixed machines. The adaptability of such machines to varying conditions in shops is no doubt what commends them to shop-owners.

As to acid and basic steel, the question is being settled by the mill owners, who are preparing to furnish the basic product as against the acid. At one of the largest mills in this country basic steel is being turned out in which it is unusual to find the phosphorus exceeding 0.01%, and the greater part of the output contains only a trace. That this will more than offset any small gain in the uniformity of the product of acid furnaces, which is no doubt due to the better stock used, will certainly be admitted by most users of steel.

As great a problem is presented in what paint to use as in any point in the paper. During the past two years, each engineer has had his favorite paint, one for painting work at the shop and still a different kind in the field. After seeing scores of brands used, the writer has come to doubt if any paint is wholly good or accomplishes its purpose. There is certainly a growing assurance among engineers that linseed oil is not the proper shop coat, and carbon primer is the favorite as a substitute. Experience shows the change to be a wise one, as it forms an elastic covering and is said to act chemically on the surface of the metal. What to do to remove the scale from steel before getting this first coat is a question. Will the mills devise some way to free their product from scale, or will the buyer pay to have the

Mr. Fowler. steel pickled? This is a much greater question than the field coat, as any of a dozen paints are first class for this, with the lead and graphite paints counted best. This coat should always be a different shade or color from the shop coat to make it easy to see when all parts are covered.

That the granitoid caps to exclude moisture from the pedestals are excellent is true, but it is a question if Portland concrete, properly crowned, would not have been sufficient.

The proportions for concrete are such as would give excellent results in practice, and if care is used these proportions would give satisfactory results under water. On some recent foundations, exactly these proportions were used by the writer and the concrete deposited under 15 ft. of water; when the work was pumped out, the concrete was found to be very uniform and set firm and hard. The uniformity was accomplished by depositing it through a tube, the first filling of the tube being accomplished by sliding paper sacks filled with concrete into the tube until above water level. For such work as pedestals, proportions as high as one-four-seven for Portland will be found to give much better results when the voids in the stone do not exceed four-tenths, than the more frequently used one-two-four natural cement concrete.

The limit for plate girders has been much extended, and it is customary for bridge shops to have orders booked for many spans at a time, from 70 to 125 ft. in length, while a few years ago riveted lattice spans would have been used. The usual limit for plate girders does not, however, exceed 90 ft. The great difference in cost is in the cheaper erection of plate girders, as they can be placed in position as complete spans during the intervals between passing trains, as was done on the Cleveland, Akron and Columbus Railway during the past year, where each complete span weighed about 40 tons. The girders were so designed as to go between the trusses of the old Howe truss spans, after the old deck was torn away.

The limit usually adopted for crimping stiffeners is beyond 36 ins. in depth, below which depth fillers are used. Some loss in stiffness is caused by the omission of the fillers, but the same weight of metal could more effectively be added to increase the size of the stiffeners.

Of the columns used, the two channels and one beam would find most favor in a shop, as the Z-bar column is difficult to keep from twisting during the punching and riveting. There is, however, a chance for some person to design a column which will meet the objections to which the different designs are subject, that is, a column where all the rivets are easy to drive, that does not twist so easily in making, and will have more satisfactory methods of detailing, as regards the development of the strength of the column as a whole.

The experiments as to the pressed threads are very interesting, and such threads should certainly be used for many cases where bolts are employed under heavy stress, such as anchor bolts and main connections where rivets cannot be put in. Mr. Fowler.

It is to be hoped that the author will give fully the results of the experiments on angles connected by one leg and star struts, as these are in such general use that the information will be awaited with interest. They affect not only the class of structures under discussion, but more particularly the construction of mill buildings.

It cannot be too firmly impressed on the young members of the profession, that one or two rivets do not make a connection. Even if the rivets are driven tight at the time the work is done, one rivet in a two-rivet joint may work loose and then it is left for one rivet to ward off accident, when, perhaps, the structure has been subjected to heavier loads than those for which it was designed. The writer had supposed that spans of any size where the riveted members did not intersect on centers of gravity was a thing of the past, but a recently constructed riveted bridge of 100-ft. span was seen in a western city, with no attempt made to have the members intersect correctly. This lack of design has become so exceptional, however, that anything of the kind is very noticeable, and most of the bad features of the older elevated roads which are mentioned are, happily, things of the past. While there is much room yet for the improvement of steel structural designs, there is reason for congratulation that there is a constant demand for the best in both material and design.

SAMUEL TOBIAS WAGNER, M. Am. Soc. C. E.—The question of sub-punching in order to obtain the accurate matching of rivet holes by subsequent reaming is one that, without doubt, is conducive to the best results as far as perfect riveting is concerned, although it has been the experience of the writer that the engineer who assumes that by this means he will obtain good matching of holes together with the removal of the $\frac{1}{16}$ in. of injured metal around the holes will deceive himself. The same experience, however, leads him to believe that no serious injury to the metal will result, even if the higher limits of what is usually specified as medium steel are used. The inaccuracies in the holes alluded to are specially noticeable in the case of long plate girders where the web plates are rolled in long lengths and the chord angles have rivet holes in both legs, the stretching of the metal in the long chord angles producing the trouble. Mr. Wagner.

The writer cannot too heartily agree with the statement that real reaming can only be done with rigid reamers, although in poorly matched holes the removal of the injured metal in the holes will not be entirely accomplished, as would be the case if the reamer were allowed to follow the hole. He has more confidence, however, in the rivet practically filling an irregular hole when the rivet is driven by hy-

Mr. Wagner. draulic power than the author of the paper has. Sub-punching and reaming must of necessity cost more than ordinary punching on account of the extra handling required and the delay in the transit of the material through the shops, and it is therefore simply a question for the engineer to decide as to whether the improved quality of the work is justified by the additional cost incurred. It is the opinion of the writer that for shop-driven rivets, and with soft steel of from say 57 000 to 65 000 lbs. ultimate strength, an ordinarily fair increase in the cost per pound is not warranted. On the other hand holes for field-driven rivets cannot match too well, and even a decidedly increased cost would be warranted in obtaining them. This is, of course, due to the difficulty of obtaining a good rivet in the field when driven by hand.

Railroad bridge work has, on account of the special care which has been given in the past to its designing, represented the best practice in structural work, but the writer agrees with the author that there is no reason why it should stand alone in this respect, and endorses the stand he has taken regarding elevated railroad work. He would even go further, and can see no reason why any structure carefully and economically designed should not receive equally as much care in the requirements of its manufacture. It is to be assumed that when an engineer prepares a specification for any work, he does it in the interest of those paying for the work, and that it has received careful consideration, and should therefore stand after the contract is made. The practice of the contractor speculating upon future changes is much to be deplored, and is a condition of things which should never exist. No changes in the requirements should ever be allowed after the contract is signed unless the very strongest reasons exist for so doing. No alternate bid should in equity be considered unless it is asked for in the proposal.

The use of basic steel is a very pertinent one at the present time, and it would be interesting if the author would give his reasons for limiting the use of this metal. The writer is of the opinion that for most purposes (eye-bars possibly excepted) the basic metal is equal to that produced in an acid furnace.

As to the remarks on cements and concrete, the results arrived at are those specified for the construction of the work on the subway and tunnel on Pennsylvania Avenue in Philadelphia, for abolishing all grade crossings on that avenue, a work costing $6 000 000. The specifications for the Portland cement (which is specified for all stone masonry and concrete) follow, and compliance with the specifications has so far been obtained without difficulty, and in some cases very much exceeded. Attention is specially called to the mortar-box tests, which are regularly taken and have proved of great value on this work.

"The acceptance of a cement to be used in the work shall rest with the Chief Engineer, and will be based on the following requirements: Mr. Wagner.

"*Portland Cement.*—Portland cement shall have a specific gravity of not less than 3, and shall leave by weight a residue of not more than 1% on a No. 50 sieve, 10% on a No. 100 sieve, and 30% on a No. 200 sieve, the sieves being the same as previously described.

"Pats of neat cement ½ in. thick, with thin edges, immersed in water, after 'hard' set, shall show no signs of 'checking' or disintegration.

"It shall require at least 30 minutes to develop initial 'set,' under the same conditions as specified for Natural Cement.

"Briquettes of neat cement, 1 sq. in. in section, shall develop the following ultimate tensile strengths:

Age.	Strength.
24 hours (in water after 'hard' set)	175 lbs.
7 days (1 day in air, 6 days in water)	450 "
28 " (1 " " 27 " ")	550 "
7 " (1 " " 6 " "), 1 part of cement to 3 parts of standard quartz sand	160 "
28 " (1 day in air, 27 days in water), 1 part of cement to 3 parts of standard quartz sand	220 "

"All cements shall meet such additional requirements as to 'hot water,' 'set,' and 'chemical' tests as the Chief Engineer may determine. The requirements for 'set' may be modified where the conditions are such as to make it advisable.

"Mortar taken from the mixing box, and molded into briquettes 1 sq. in. in cross section, shall develop the following ultimate tensile strength:

Age.	Strength.
7 days (1 day in air, 6 days in water), 1 part Portland cement to 3 parts of sand	100 lbs.
28 " (1 day in air, 27 days in water) 1 part of Portland cement to 3 parts of sand	150 lbs."

A comparison of the specifications shows a fairly close agreement in the requirements, the specifications just given being slightly harder to fill.

The specifications for the concrete on this work require the same proportions as given by the author, viz., one part of cement, two parts of sand, and five parts of broken stone, which is not required to be graded.

The question of painting is one deserving of the greatest care, and the results of any experiments must of necessity be interesting. Without entering into detail the writer from his experience warmly recommends the practice of giving the metal a coat of linseed oil before leaving the cover of the mill and after all loose black scale is removed. He believes this to be one of the secrets of the prevention of a large amount of rusting, no matter what priming and finishing coats are applied. These latter coats must of necessity vary somewhat with the locality and use of the structure, while this first precaution he believes to be essential in any structural work.

Mr. Stowell. CHAS. F. STOWELL, M. Am. Soc. C. E.—The safety and longevity of any iron or steel bridge is inversely proportional to the amount and extent of motion in the structure. Motion, as regards structures, may be divided into two kinds; dynamic, or that motion due to and inseparable from the imposition of stress, and physical, or motion of translation, which may or may not be accompanied by internal stress. Except when a bridge is moved bodily off its foundations, no failure ever has or ever can take place except as the immediate result of excessive dynamic motion. As long as a bridge contains metal in sufficient quantity and so disposed as to restrict the dynamic motion within certain limits, its life, so far as is known, will be perpetual; but as soon as the limit is exceeded in any one member, the failure of that member sooner or later is absolutely certain. In former times it was the rule, and even yet the practice obtains to some extent, to proportion bridges for stress alone without regard to motion; and many old bridges were simply statical stress sheets transformed into iron. If in any such bridges the dynamic motion was kept within safe limits it was a happy incident or accident of their construction. It is known now that a stress and section sheet is not a safe criterion of the value of a bridge, and that to insure permanence, not only the stress, but also the motion, must be considered and provided for.

When the earlier elevated structures were built, neither the loads to which they would be subjected were anticipated, nor was the subject of dynamic motion understood, and consequently these structures were soon found to lack both strength and rigidity. Remedies of various kinds have been applied to them from time to time to correct the former defect, but the latter is still obtrusively apparent to any observer. It can hardly be questioned that the life of the Manhattan elevated structure must be a limited one for this reason. Whether the limit is close at hand or still far off can only be judged by those in charge of and constantly observing the structure under its daily task. That such a limit was long ago recognized by its owners appears to be shown by these words of one of its officers published fourteen years ago: "The structure is an iron bridge for the whole length of the railway, miles in length; whether this will have to be rebuilt in ten years or fifty nobody yet knows." * The Chicago elevated structure offers a marked contrast to these older works in that not only strength but rigidity also is considered, and it is the first elevated structure within the writer's knowledge where the latter point has received any particular attention. He does not agree with the author as to the value of sub-punching and reaming. If such treatment is prescribed to cure the bad effect of punching, it is delusive. Solid drilling is the only safe course under those premises. The writer has yet to see any piece

* Report of State Engineer and Comptroller in answer to resolution of New York State Senate, March 20th, 1883.

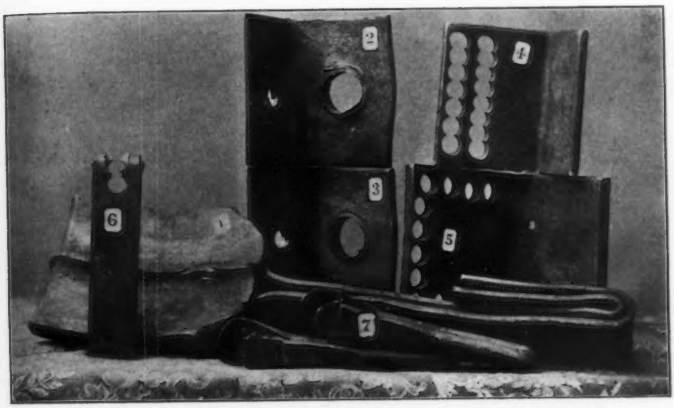

FIG. 1.

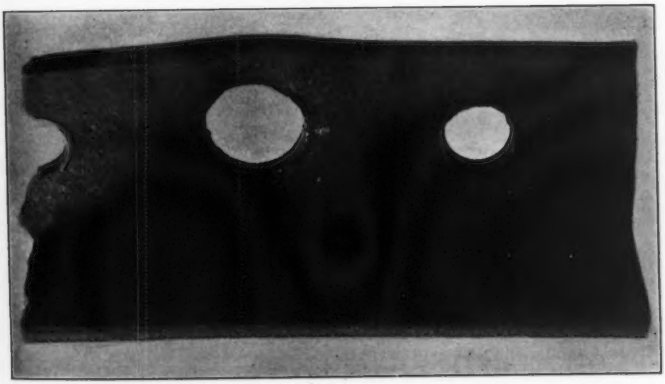

FIG. 2.

of work in which all the punched surface was removed from every hole, and unless it is so removed it is obviously useless to remove it from some and leave it on others. Instead of using material which is liable to injury in punching and then applying a remedy for the harm knowingly inflicted, it seems safer, and it is certainly cheaper, to get in the first place steel which will not be injuriously affected by punching and shearing. Such steel is not hard to get. A photograph, Plate X, Fig. 1, is submitted of some tests on steel of this kind recently used in bridge work, which has stood much more abuse than it could ever possibly get in any shop, and still without reaching its limit of endurance. These test pieces were not specially selected, but were ordinary pieces picked up at random, and the tests were not nursed in the making to produce a fine show, as is sometimes the case, but were actually made in the roughest and hardest manner. This steel was 55 000 to 65 000 lbs. ultimate, averaging about 62 000 lbs. After knowing the quality of this steel from the stock used in making it, from the process of manufacture and from its chemical analysis, and having demonstrated its properties by physical tests, the writer feels perfectly safe in using the material without sub-punching and reaming, and without planing sheared edges; far safer in fact than he would in using an inferior metal and doctoring it afterwards. This particular steel happens to be acid open-hearth, but he has no doubt that basic steel of corresponding good quality would show up equally well. This steel costs from 0.05 to 0.1 cent per pound more than ordinary steel, while the author's figures for the extra cost of sub-punching and reaming are from 0.1 to 0.2 cent per pound. Mr. Stowell.

Reaming for fair holes and not primarily to remove the surface cut by the punch is quite another matter, but with care there need be very little, if any, such reaming done. The author is certainly wrong in saying that no shop can turn out first-class work without sub-punching and reaming or drilling. The writer has been accustomed to specify that when the rivet holes match sufficiently to let a cold rivet through, but not a hot one, they may be drifted fair, but any greater degree of mismatching must be corrected by reaming. In a shop where some care is taken with the punching, the amount of reaming under this specification is exceedingly small. The habitual use of the reamer to get fair holes prevails generally where the punching is piece work. When a man's pay depends upon the number of holes he makes in a day, he is not likely to be over careful where he puts them, especially if he knows some one will follow after him with a reamer to correct his inaccuracies. All this is unnecessary with a little care at the punch. Moreover, the writer is of the opinion that the rivets themselves hold better and are stronger in punched than in drilled or reamed holes.

Another consideration in regard to reaming to remove injured

Mr. Stowell. metal is this. Such holes are always punched in the first place, and often carelessly, as the man at the punch knows they are to be reamed afterwards. Before reaming, the work has to be fitted up and bolted through these punched holes, a process accompanied by more or less heavy drifting according to the degree of inaccuracy in the punching. If the original punching has started a crack in any hole, it will surely be extended by any drifting done on that hole. Can one always be absolutely certain that, whatever the amount of metal reamed out, it is enough to extend beyond the limit of any such crack? The writer thinks not.

One should, of course, use all reasonable precautions to get good and accurate work which will not require abuse of the metal in order to get the parts to go together. If in addition one is sure of having metal which can safely stand far more abuse than can ever possibly be put upon it, should it happen to get any, and which need not be gone over minutely to be sure that every bit of sheared surface has been removed, it is greatly conducive to a good night's sleep.

The steel specification for the Chicago elevated work called for open-hearth metal having an ultimate strength of 60 000 to 68 000 lbs. per square inch; elastic limit, one-half of ultimate strength; percentage of elongation, ultimate divided by 1 500 000 (corresponding to about 25%); percentage of reduction, twice that of elongation; quench bend, 180° around a diameter equal to the thickness of the test piece, and drift test to show an increase of 50% over original diameter of punched hole. The chemistry was prescribed only for phosphorus, which was not to exceed 0.08% for acid, and 0.05% for basic steel. This is a very good specification as far as it goes, and far superior to many in use. But the writer believes that not only the phosphorus, but also the sulphur should be limited. He is aware the manufacturer will claim that, inasmuch as sulphur is a red shortener, it may safely be left alone, as any excess will show itself in the breaking up of the steel in rolling. But this is not all. Experience has demonstrated that sulphur may exist so near the limit of red shortness that, while it does not cause the steel actually to disintegrate in rolling, it may leave the rolls full of minute fractures (micro-sulphur flaws) which cannot be detected by the eye, but which are liable to extend under stress and ultimately cause the fracture of the piece. For this reason the sulphur content should be kept well within the danger limit.

The author's requirement of a drift test showing 50% increase in diameter of punched holes is a good and reasonable one, but too much stress should not be placed on the drift test as indicating the quality of steel. If it does not stand a moderate amount of drifting, the steel is certainly poor, but if it does stand it, it by no means follows that it is good or even passable. The evidence of the drift pin should be considered as corroborative only, not absolute, as is the tendency in

some quarters. There is a bridge specification very widely used and extensively copied throughout this country which provides a drift test showing an increase of only one-third in the diameter of punched holes, and making such a test the criterion for reaming and planing or their omission. To show how utterly worthless such a test is, the writer submits an illustration (Plate X, Fig. 2) of a piece of angle iron with a punched hole drifted from $\frac{13}{16}$ to $1\frac{9}{16}$ ins. diameter, or about 58% increase, and still without reaching the possible limit of drifting. In other words, this piece has filled the requirements of the specification and about 25% more, and under its requirements might be used without reaming or planing for any kind of bridge work under any circumstances. Yet the steel is so poor that the piece shown in the photograph broke off while trying to bend the angle iron to a curve of 40 ft. radius. The peculiar feature of that specification is not only that it lays such stress on this worthless drift test, but, even should the steel be so unspeakably bad that it cannot stand this drifting, still it may be used provided only the holes are reamed and the edges planed. Mr. Stowell.

The chemistry of this piece of steel is as follows: Carbon, 0.130%; phosphorus, 0.101%; sulphur, 0.056%; silicon, 0.040%; manganese, 0.591 per cent.

The analysis stamps the steel as a quite ordinary grade of (probably) Bessemer metal, and on the analysis alone it would be rejected for use in any important place; but the specification mentioned would permit its use for any purpose, as that specification ignores both chemistry and process of manufacture. The writer believes more poor steel has probably been put into American bridges under that specification than under any other ever written, and the reason why it does not more often show itself in failures is because manufacturers generally make a much better quality of steel than that specification would permit the use of. There is, fortunately, a limit to poverty in steel beyond which it does not pay to try to make it. When more than a certain percentage cannot be run through the rolls whole, the cost of such of the product as can be finished more than offsets the saving in the use of cheap stock. The tendency in steel making, too, is in the direction of continued improvement in its quality, and most manufacturers nowadays habitually turn out a pretty fair grade of metal, so that the purchaser under such a specification as is mentioned generally gets now a much better article than he calls for.

The author's experiments on the relative value of angle irons connected by one and by both legs are in accord with facts long known to those familiar with riveted construction. A good many modern specifications stipulate that angles must always be fastened by both legs or the section of one leg only be considered as available for stress. If it were true, or even approximately so, that the strength of an angle iron fastened by one leg is that of this leg only, a great many old riveted

Mr. Stowell. bridges would have broken down long ago, but they persistently refuse to collapse and verify the theory.

The author's design for an elevated structure is, on the whole, a distinct advance over all previous efforts in that line, and the care and study expended on the subject have resulted in a structure which apparently leaves little further improvement possible. The use of solid web girders instead of open web, the large and substantial knee braces at tops of columns, the scientific arrangement of the lateral bracing and the proportioning of columns and anchorages to withstand all possible horizontal as well as vertical loads, are particularly good features; and the writer ventures the prediction that future elevated roads will be largely modeled after this one.

The proposed design for an ornamental structure for city streets is a generally beautiful and tasteful design, unfortunately not likely to be realized in practice soon. There is one feature about it which the writer does not admire, namely, the making of the outlet for drain pipes through animals' mouths. The representation of a beast's head in the act of vomiting is not a pleasing spectacle.

Mr. Connor. E. H. CONNOR, Assoc. M. Am. Soc. C. E.—The stresses used in the various members under varying conditions, and the unit prices assumed in the comparative designs, and their costs, are all omitted in the paper. The several points mentioned from *A* to *P* should, without doubt, receive due consideration, but the author does not state when he deems the columns "properly designed to provide sufficient strength," etc. The same may be said of many of the other articles. As all elevated railroads in Chicago are having a hard time financially, economy must be a very important factor in a design for that city. Certainly safety must not be sacrificed at any cost, but too much money should not be spent to overcome non-injurious vibrations. Vibrations are inherent in all metallic structures, and should simply be kept within proper limits.

The longitudinal girders used on the Northwestern Elevated road have been carefully designed and are well braced. Lattice girders are more pleasing in appearance, and admit more light to the street beneath. They are not so satisfactory for rigidity and maintenance as plate girders. The cost for 50-ft. spans is about the same. The columns used on the same road were very difficult and expensive to manufacture on account of the large plate, over 6 ft. square, with sectors cut out of the lower corners, on account of the connection taking the longitudinal thrust, with its irregularly cut plates, and on account of the many parts, over seventy in each column, which required the columns to be handled several times in assembling and riveting.

It is proper to allow high unit strains in the metal when the live load, dead load and bending moment are all considered; 15 000 lbs.

per square inch would not be too much for medium steel columns on a tangent. The longitudinal thrust due to an application of brakes on the entire train is distributed by the rails, floor and girders over a considerable length of the structure. If it is considered distributed over a distance equal to twice the length of the train, and carried by the columns within that distance, the longitudinal vibrations would be confined to small limits. Mr. Connor.

Columns of more pleasing appearance and sufficient rigidity can be built more economically of 15-in. channels, flared at the end to receive the stringers directly without cross-girders, than those adopted by the author. The channels may be strengthened near the base by angles when it becomes necessary in long columns.

The maximum fiber stress due to the Northwestern loading, longitudinal and transverse bending, assuming the longitudinal thrust to be two-tenths of the entire weight of a train 200 ft. long, and distributed over 320 ft., or 8 bents, in a column 16 ft. high built of two 15-in., 33-lb. channels would be about 12 500 lbs. per square inch, a perfectly safe stress. The sectional area of this column is less than that of the one used, and no longitudinal tower bracing is required. The saving in columns and cross-girders would be considerable. Such columns have been in use in New York for many years, and are to-day satisfactorily performing their duties, though the vibrations are excessive, some of the details poor and the amount of care given them very small.

The rigidity could be increased by altering and strengthening the details. Longitudinal brackets riveted to the columns and bearing against stiff cross-frames between the stringers could be introduced. The writer sees no reason, however, for discarding entirely the main features which are economical in material and shop labor.

The writer is glad to see the firm stand taken by the author in regard to punching and reaming rivet holes, and is sorry to note that facing the end angles of the longitudinal girders, almost equally desirable, was not required. The additional cost is very small. Such workmanship decreases the factor of ignorance as to existing conditions and permits the use of higher unit stresses.

HENRY W. HODGE, M. Am. Soc. C. E.—The paper will undoubtedly be of great advantage in improving the general designs and details of elevated railroad structures, though it is to be hoped that American cities are not to be afflicted with any large amount of such work. Æsthetics in an elevated railroad is, in the writer's opinion, purely a matter of imagination, and such structures cannot but be unsightly and ruinous to the appearance and comfort of any city street. Mr. Hodge.

The writer cannot agree that it is advisable to reduce the ultimate stress on basic steel to 61 000 lbs., nor has it been his experience that basic steel is less uniform in quality than acid. The material for the

Mr. Hodge. Duluth and Superior Bridge was ordered under the following specifications: Ultimate, 63 000 to 70 000 lbs.; elastic, 55% of ultimate; elongation in 8 ins., 22%; reduction, 40 per cent.

The use of either acid or basic steel was allowed, except that acid was required for eye-bars. The acid was not to contain more than 0.08% of phosphorus, or the basic more than 0.04% of phosphorus. No difficulty was experienced in getting material of these qualifications, nor did the manufacturers object to it as difficult to make, and the amount of material rejected for failing to come up to these specifications was so small as to be hardly worth consideration. There was about 1 000 tons of acid steel and 2 000 tons of basic steel, and the maximum and minimum values obtained from all specimen tests, including the tests on material rejected, were as follows:

	Acid steel.	Basic steel.
Ultimate.....	58 710 to 74 840	51 780 to 76 700
Elastic.....	31 500 to 46 660	32 600 to 49 100
Elongation in 8 ins.	14.5% to 34.5%	17.5% to 33%
Reduction	25.6% to 63.7%	31.7% to 65.3%
Phosphorus.....	0.018% to 0.08%	0.007% to 0.036%

Considering there was twice as much basic as acid material, the writer thinks these results show basic steel to be not less uniform than acid. Of course, these values are all extremes from a very large number of tests, and in some cases are caused by hard or soft spots; so while they may not show the average character of the material, they at least show what extreme variations may be found in a large amount of material.

In this structure the metal for the wheel treads of the turntable was required to fill the following specification: Ultimate, 70 000 to 80 000 lbs.; elastic, 50% of ultimate; elongation in 8 ins., 20%; reduction, 35 per cent.

The results of tests on basic steel were: Ultimate, 70 980 to 72 050 lbs.; elastic, 47 240 to 49 150 lbs.; elongation in 8 ins., 24.5% to 27.5%; reduction, 50.9% to 55.2 per cent.

As such a grade of basic steel can be made without greatly increased cost, the writer sees no reason for putting the ultimate so low as 61 000, and would advocate from 63 000 to 70 000 lbs. In the enumeration in the paper of faulty details, it seems to the writer that a number are not details at all, but main principles, as the designer who does not use sufficient bracing between longitudinal girders, or put sufficient rivets in joints, or proportion the chords of girders for bending as well as direct stress, or proportion columns for the horizontal as well as vertical loads, or use bases large enough to carry the loads under columns, is not worthy of the name of engineer. These and several other so-called details are such elementary matters, now so

generally attended to, that it is certainly useless to call any reputable engineer's attention to them. Mr. Hodge.

The writer thinks it unnecessary to increase the theoretical number of rivets in a member, if such number is small, for fear one may be loose, as such a possibility should be guarded against by setting proper valuations on rivet-bearing and shearing. If one started to "guess" how many extra rivets should be allowed at each joint, why trust to figures at all? Gravity lines should intersect in a point, of course, to prevent torsion on the riveted joints.

Nor does the writer see any reason why lacing should not be relied on to carry horizontal thrust in the column, as the lacing is generally on each side of the column, and in most cases has two rivets in each lattice, so it will be necessary for four rivets to be loose instead of one, as stated in the paper, to destroy the efficiency of the lattice. The necessity of giving away material to avoid any such improbable contingency is difficult to see. As to æsthetics, the writer believes that most engineers had by all means better call in an experienced architect to give assistance in such matters, as he thinks such a man's idea would doubtless be a great improvement on the one suggested.

BERNT BERGER, Assoc. M. Am. Soc. C. E.—The author states that the results of his examination of previously constructed elevated railroads amount simply to the accumulation of a great mass of information exemplifying "how not to do it." It appears, however, as if he has consciously or unconsciously made use of several features of the older systems of elevated railroads. Mr. Berger.

In all the early elevated railroad structures in New York the columns were anchored to the foundations, and the anchor rods were run through to the bottom and not stopped off in the middle of the mass. The writer does not mean to say that such anchorage is necessarily a point of excellence, but the idea is an old one. The rigid connection of the cross-girders to the posts was used as early as 1878 in the City Hall branch of the elevated railroad in New York. Here the columns are formed of two 15-in. channels latticed and inserted into deep pedestal castings, which are anchored to the foundations. One channel is cut off under the bottom flange of the cross girder, which rests on it, and the other channel extends to the top flange of the girder and is riveted to its vertical end angles. Theodore Cooper, M. Am. Soc. C. E., who had charge of this work during its construction, copied this detail in his design of the elevated structure for the Pittsburg Junction Railroad in 1883, and the same method of connecting the cross-girders to the columns has been used in several other elevated railroad structures.

In Fig. 35 is shown a rigid connection of cross-girders to columns, where the former overhang the latter, employed by Mr. Cooper in his design for the Suburban Rapid Transit Railway in New York in 1886. The channels of the columns are cut off under the bottom flange of the

Mr. Berger. cross-girders, a batten plate extended up on each side of the girder to which are riveted two angles which again are riveted to web-stiffening angles on the girder. This top connection gives all the required rigidity to the structure. The foot of the columns is not anchored to the foundation, but rests on a cast-iron pedestal which raises it above the dirt and moisture of the street. The same cut also shows the expansion pocket. The pocket is particularly strong in the girder seat, the vertical webs of the channels precluding any possibility of undue yielding of the seat and working of the rivets.

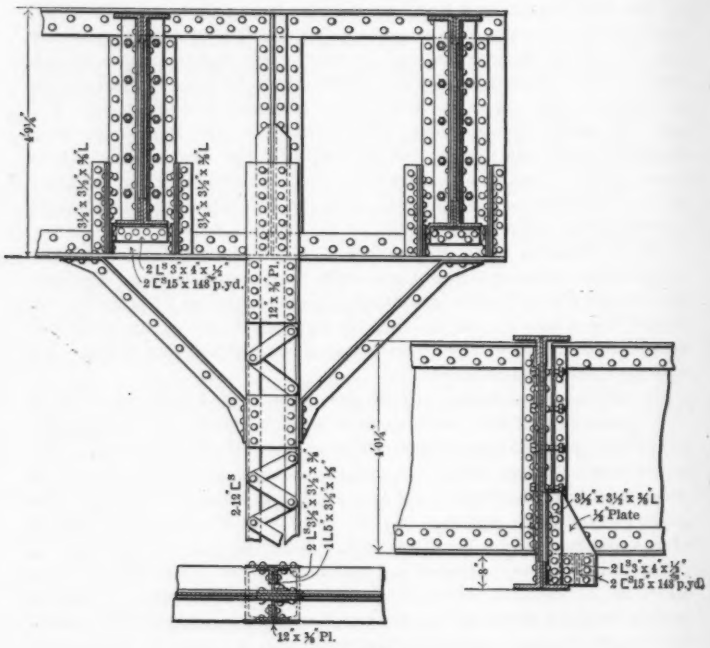
4'9½"
3½" x 3½" x ⅜" L
3½" x 3½" x ⅜" L
2 L 3" x 4" x ½"
2 C 15" x 14# p.yd.
12" x ⅜" Pl.
2 12" C
2 L 3½" x 3½" x ⅜"
1 L 5" x 3½" x ⅜"
12" x ⅜" Pl.
4'0¼"
3½" x 3½" x ⅜" L
½" Plate
2 L 3" x 4" x ½"
2 C 15" x 14# p.yd.

FIG. 35.

Fig. 36 shows the expansion pocket for the railroad stringers of the Asylum Street improvements at Hartford, Conn. This elevated railroad structure was built in 1888, is about 670 ft. long, in part on a curve, and carries four tracks and three platforms. It was designed for Class A of Mr. Cooper's specifications. The pocket is a very strong and rigid one, the side plates and angles having been extended the full depth of the cross-girder. In the same structure stiff transverse sway bracing was used.

Both expansion pockets are provided with $\frac{7}{8}$-in. safety bolts to prevent any possibility of the contraction of the structure under falling temperature becoming concentrated at any one pocket. Mr. Berger.

The introduction of braced towers is admirable, and it is the author's good fortune that his structure was so located as to permit it. The writer is in accord with him in his strong plea for reaming of riveted members, which reaming must, however, by no means be understood to do away with careful work in punching.

WALTER T. SMITH, Jun. Am. Soc. C. E.—The writer, who was connected for over two and one-half years with the Wabash Avenue ex- Mr. Smith.

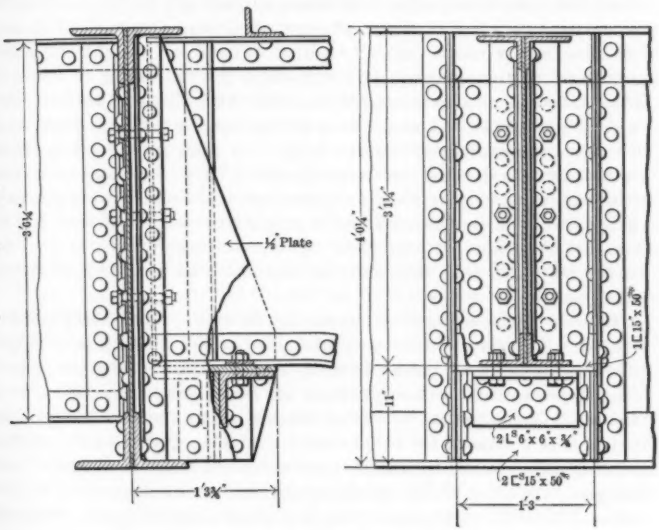

FIG. 36.

tension of the Lake Street road and with both the Northwestern and Union Elevated construction, touches on the following features, not in a spirit of criticism, but rather that some views contrary to those of the author may be noted and corrected if wrong.

The first subject is the radical change over other elevated road construction in the introduction of tower spans, 23 ft. 6 ins. center to center of columns, braced both longitudinally and transversely to the column foot, as shown in the details. The reason given for this is the fact that express trains are to be run over the surface at a rate of 40 miles per hour, making this condition necessary to take the traction force due to the braked train. This assumption was made, evidently,

Mr. Smith. owing to the fact that every fourth span has an expansion joint, thereby making it impossible to direct this longitudinal force into more than four spans or sixteen columns at one time, or at least during the period of maximum stress. This would be true without doubt were the structure proper only to be taken into consideration, but this view does not show all the facts of the case.

The maximum condition of stress is due to a loaded train consisting of one motor car and three trailers, weighing in all about 180 000 lbs., running at the rate of 40 miles per hour. It is found necessary to stop this train in the least possible time. By knowing the distance which the train travels after brakes are applied and the time necessary to bring it to a stop, the calculation of the force of traction or thrust could be made without difficulty. This whole force would be applied to a single section between two expansion joints, owing to the fact that the train length is about 150 ft., while the distance between the expansion joints is, at times, more, were it not for the deck work, and this changes existing conditions totally. In each track system there are four guard rails and two running rails. These six rails form the structure into a mass in such a manner that if a strain is put upon any part of the deck, it is carried over a large extent of its surface. It is true that the space for expansion of the running rail would tend to cause a sliding of that rail were any considerable longitudinal strain put upon it.

In case this sliding does occur, the friction of the spike and tie bearing will convey the thrust into the tie, and from there it must either be taken up by the tie bearing of the girder or by the guard rail. Reason would certainly denote the latter, for the ties and guard rails are bolted together in such a manner as to render it impossible for one to act without the other, while the connection between the tie and the girder is not by any means a complete one, for if such were the case, expansion of the metal would injure the alignment of the deck. This last statement is true to a greater extent of the roads in question than on the Metropolitan Elevated of Chicago, for that road has bolted all ties to the flange of the girder while the Northwestern and Union Elevated use hook bolts on each second tie only.

The conclusion drawn from these conditions is that the stress due to braked trains is not conveyed, to any extent, to the columns. It would be unreasonable to say that this stress does not affect the columns at all, for the fact that the longitudinals and columns are riveted together makes it impossible for one to act without some effect on the other. At the same time no bending can be produced upon the column, for it is counteracted by the deck. Were the longitudinals made continuous for long distances and the only connections with the columns were by bearing plates or rolls, so as to leave absolutely no resistance but that of a body at rest, there would be no direct longitud-

inal motion. This would have a tendency to aggravate the transverse stress greatly, in that it would be continuous, and for that reason, if no other, the author's idea of carrying the columns to the full height of the structure is to be commended. Mr. Smith.

A point of contention might be as to whether the mass of the structure is in stable or unstable equilibrium. The fact that a large body is supported by a column of small area in proportion to its size, or a number of them, does not make it unstable, provided the forces acting upon that body do not tend to move it to a sufficient extent that its own weight is added to the forces already employed. Were the action of the train large enough in proportion to the structure affected to produce a tendency in the mass of the steel to move in the direction that the train travels and thereby lend its own weight to the force of the train, the bending of the columns would be severe. This is not, however, within the bounds of reason and can be at once dismissed. It will be assumed that the action of this longitudinal thrust is wholly taken up by that portion of the structure upon which the train runs, that is, upon two of the longitudinals with the deck. This assumption is greatly on the side of safety, for the design of the structure makes it impossible to strain this one-track system without affecting to some degree the other three, and especially that on the same side of the center. If the force is confined to this single track, however, and its action does not extend more than twice or three times the length of the train in either direction, there is a weight equal to three times that of the train which must needs be set in motion before bending can occur. Were it possible to design a column section in any case, which would carry the load due to compression, without longitudinal strength, then some metal might, in this case, be necessary to withstand any light stress caused by thrust. This being impossible, however, the conclusion is drawn that any metal used in any part of the structure to withstand horizontal thrust in a longitudinal direction is superfluous and a needless expense. This same rule could be applied to the transverse bracing of the towers in a four-track structure. The force of impact is not severe, and the width of the structure makes it perfectly stable. This in no way applies to lateral systems used to stiffen girders, or to cross frames.

The question as to what construction of guards is the most useful seems to be one of great importance and interest to all who are concerned in any way with elevated roads. On the lines under consideration a 6 x 6-in. inner guard is used, while the outer one is 6 x 8 ins. Would not a 6 x 8 in. be better for the inner rail? Without doubt, it is the more important of the two, and should the car jump the track, more lifting power would be necessary to carry it over the high rail than the low. It is true that in case of a blow the high rail would be more likely to split than the low, yet it would seem very doubtful if

Mr. Smith. a blow of that severity could be produced on the inner rail, which is but 4 ins. from the track rail.

The outer guard to a large extent is a matter of sentiment. Its only practical use can be that it stiffens the outer ends of the tie and might in that way prevent a wreck. Could the outer guard be placed far enough from the track rail to allow the entire right wheel of the car to pass over the inner guard before the left wheel struck the outer guard, its practical use would be established. As this is not possible in present construction, the matter need not be discussed. The outer guard, however, lends an appearance of security for the traveling public which possibly warrants its use.

Mr. Treadwell. LEE TREADWELL, M. Am. Soc. C. E.—Few engineers will deny the fact that an elevated railroad should be built, not only to carry the assumed live and dead loads, but also to resist the longitudinal thrust of braked trains, the centrifugal force of moving loads on curves, and a lateral force on tangents due to wind pressure and the oscillations of moving trains. At the same time, however, each designer will probably have his own ideas as to how the longitudinal forces should be distributed. Judging from most of the elevated roads now in existence, it would seem that the general practice has been to assume that the track and guard rails make the structure continuous over the expansion joints, and therefore, that the longitudinal thrust of braked trains is distributed over a long stretch of track. It is true that the track and guard rails do give to the structure a certain amount of continuity, but it is an uncertain factor and should not be counted upon, except in special cases. The author's method of treating that portion of the structure between expansion points as entirely independent and separate, and in designing it to resist all the forces that can be applied between those points, is undoubtedly to be commended; in fact it would seem to be the most scientific way of solving the problem. Granting, however, that so far as strength is concerned, the track does make the structure continuous, the author's method would still be preferable, for it leads to the attainment of one of the most desirable qualities in an elevated railroad, namely, that of rigidity.

Again, few will question the author's statement that an elevated railroad should be built with the same degree of excellence in respect to quality of material and workmanship as that of any railroad bridge, and he is probably not going too far when he intimates that it might be well to make the details and connections even more nearly perfect in the former than in the latter. The reason for this is, as stated in the paper, that a railroad bridge will generally receive its maximum live load at comparatively long intervals only, while in the case of an elevated railroad the assumed maximum live load may be applied many times a day. Another reason why the greatest care should be taken in detailing an elevated railroad is that owing to the frequency

of the trains, it is in an almost continuous state of vibration and tremor, which tends to work the connections loose and weaken the structure. Mr Treadwell.

In respect to the use of "unreamed soft steel at a low intensity of working stress, or reamed medium steel at a higher intensity," the author shows his good judgment in his final decision to use medium steel throughout. If, however, it be claimed that rigidity is one of the essential qualities of an elevated railroad, it must be admitted, also, that the use of "soft steel at a low intensity of working stress" has at least one advantage over "medium steel at a higher intensity." The advantage depends on the difference in the unit strains used, for, as the elastic coefficients of the two metals are equal, the deflections and consequent vibrations will be in direct proportion to the fiber strains used in designing. It necessarily follows, therefore, that, everything else being equal, the lower the unit strains used, the more rigid will be the structure.

It is also claimed by some engineers that soft steel is better suited than medium steel to resist suddenly induced strains; and for short-span bridges in particular, the use of the softer metal is urged. The author himself half admits these claims to be well founded. Then, if it be true that the nature of soft steel is such as to make that metal more reliable than medium steel under shocks of greater or less intensity, it would only seem proper under those conditions to strain the two metals about alike, up to, say, 8 000 or 10 000 lbs. per square inch, assuming that the advantage gained in the softer quality of one metal is sufficient to offset the greater elastic limit of the other. If it be taken for granted, also, as claimed by many manufacturers, that the reaming out of the cracked metal around punched rivet holes does not materially increase the strength of the section, and especially its elastic limit, then soft steel would seem to be an ideal metal for an elevated railroad, and there would undoubtedly be a considerable saving in cost by using it in preference to reamed medium steel.

In the writer's opinion most of the advantages claimed for soft steel are entirely problematical, and, except for special purposes, he does not advocate its use. In point of endurance it has been pretty well demonstrated among mechanical engineers that soft steel is far inferior to a higher carbon metal; and there seems to be no good reason why civil engineers should not profit by the experience of their mechanical brethren. Take, for example, car axles, crank shafts, piston rods, and steel rails—how is it that they manage to stand up so well when strained in almost every conceivable way? Does not the chief reason lie in the fact that they have a high elastic limit and ultimate strength? That is certainly the most plausible explanation. It may be claimed that car axles and crank shafts are made of a better quality of metal, which is improved by forging; but, however, that

Mr. Treadwell.

may be, the same can hardly be said to be true of steel rails, for they are rolled from Bessemer steel, and have an elastic limit usually not below 50 000 lbs. per square inch. It would seem to follow, therefore, that, other conditions being the same, the capacity of steel to resist indefinitely the application of externally applied forces without injury to itself is measured by its elasticity. The higher the elastic limit, the greater are its resisting powers and the longer will be its life.

Why, then, it may be asked, is soft steel so often called for? One reason is, that some engineers believe it more nearly approaches the nature of wrought iron, and that it is, therefore, more suitable for short-span bridges; in other words, that it is more reliable than medium steel under shocks and suddenly induced strains. As before stated, these claims do not seem to be thoroughly founded on facts. Actual experience with both metals under heavy strain, especially in the field of mechanical engineering, where the wear and tear is more easily observed, is constantly adding additional proof of the inferior quality of soft steel as a durable and serviceable metal.

Another and probably more important reason why unreamed soft steel is so widely favored is due to two facts; first, it is cheaper pound for pound than reamed medium steel; and, second, most manufacturers favor its use because it is claimed to be easier to make and easier to manipulate in the shop. Taken as they come from the rolling mill, there is practically no difference in the cost of the two metals, but in the shop it must be admitted that the softer and more pliable a metal is, the easier and less expensive are the operations of straightening and punching. The difference in manipulation is so slight, however, that most manufacturers will bid the same pound price on unreamed work whether it be of soft or medium steel. Nevertheless, pay the contractor the added cost of straightening, punching and reaming, and he would still rather use soft steel and punch the rivet holes full size, simply because the operation of reaming retards the progress of work in the shop, while his interests require that it be pushed through in the shortest time possible. It is a business proposition that no contractor can afford to ignore in these days of strong competition, especially when there is a large demand for work to be delivered in a limited time. If the manufacturer be paid for the extra work of sub-punching and reaming, it is not clear why he should oppose it on any other grounds than that it reduces the output of his shop. Conditions are changing somewhat, though, and fewer objections to reaming are heard now than formerly. Most of the leading bridge companies are well equipped for drilling and reaming, and they are still making improvements in their equipment along that line. The chief engineer of one of the larger companies told the writer recently that the reaming capacity of his shop was about equal to its riveting capacity.

Mr. Treadwell.

How much cheaper is the finished product of unreamed soft steel than reamed medium steel? According to the author, the cost of reaming varies from one-tenth to two-tenths of a cent per pound. To illustrate further, suppose bids to be invited on 1 000 tons of structural work erected and painted, first, on unreamed soft steel; and second, on reamed medium steel. The bidders would make less than 10% difference in the pound prices for the two metals. The author states, also, that reamed medium steel may be strained 10% higher than soft steel. Some specifications allow 15% difference. The author's statement, therefore that "as far as the total cost is concerned, it is immaterial whether unreamed soft or reamed medium steel be used," is rather conservative than otherwise in favor of the latter metal. Then there still remains in favor of medium steel the advantage gained in the superior workmanship due to reaming; such, for instance, as the perfect matching of rivet holes in the main members and the consequent better fitting of all the parts. It is self-evident that the more nearly perfect the joints and connections of any structure are fitted together, the more rigid and durable it will be.

By soft and medium steel, the writer refers to metals having average ultimate strengths of 56 000 and 64 000 lbs. per square inch, respectively. It may be added that no such distinction is observed by the majority of rolling mills. With them, the limits govern rather than the averages called for in the specifications. In specifications for soft steel the ultimate strength is generally limited to 60 000 or 62 000 lbs. per square inch, while for medium steel it is generally required that the ultimate tensile strength shall be not less than 58 000 to 60 000 lbs. per square inch. Here there is a maximum overlap of 4 000 lbs. per square inch. The engineer who wrote the specifications for soft steel could not be persuaded to change to medium, and the designer who called for medium steel would be highly indignant if asked to accept the softer metal instead. The truth of the matter is, however, that many of the mills are daily filling orders for both specifications from practically the same grade of metal. Its ultimate strength averages from 58 000 to 62 000 lbs. per square inch, and as the limits of neither specification are transgressed, both the engineer and the designer are well pleased with what they get.

This practice on the part of the rolling mills of striking an average between soft and medium steel, rather than any lack of uniformity in the basic open-hearth product, is possibly responsible for the facts which led the author to state, that "the reports of the company's inspectors indicate that the basic steel is not quite so uniform in quality as the acid; and that it may prove advisable in future specifications for basic medium steel to reduce the average ultimate stress limits from 64 000 to 61 000 lbs. per square inch."

Excluding metal rolled for rivets, it is probably safe to say that

Mr. Treadwell.

90% of the soft and medium steel rolled at the present time for structural purposes has an ultimate strength between the limits of 56 000 and 66 000 lbs. per square inch, a range of only 10 000 lbs. which some manufacturers claim should be allowed.

It is possible, then, that authors of specifications are splitting hairs and quibbling over the difference between soft and medium steel to no purpose. It is to be hoped that such is not the case, but it must be confessed that there is some ground for such a declaration. Why not adopt a single standard at once and be done with it? There are three courses open; first, accept and be contented with the present imperfect system; second, retain the distinction between soft and medium steel, but require that the metal furnished shall have an ultimate strength equal to that called for in the specifications, and not an average 2 000 or 3 000 lbs. above or below; third, abandon the distinction between soft and medium steel, and adopt, for all general purposes, a uniform metal of the highest grade the manufacturer can make consistent with the cost, regularity and reliability of the product. At present, an average ultimate strength of from 60 000 to 62 000 lbs. per square inch would probably be about right. It would be necessary, of course, to continue to make rivets of soft steel; and for very long span bridges it would be advantageous to use a higher grade of steel, having an ultimate strength of, say, 62 000 to 70 000 lbs. per square inch, even if the cost should be increased somewhat.

If it were proposed to abandon the present distinction between soft and medium steel, there would probably be a vigorous protest from the engineering profession in general; but, however that may be, much may be said in favor of a single standard for structural steel. In the first place, the difference between the ultimate strength of such a standard and the ultimates now called for in specifications for soft and medium steel would be insignificant when reduced to the corresponding working stresses, especially when it is remembered that authors of specifications differ greatly in the unit stresses allowed in designing.

Again, if a single standard were adopted, the manufacturer would doubtless feel disposed to improve his metal in the direction of a higher elastic limit, and at the same time preserve its uniformity and toughness; but so long as he is required to make both soft and medium steel upon specifications that overlap, so long will the metal produced be neither soft nor medium steel in the strictest sense, but an approximate average between the two. Then, too, if the manufacturer were required to make only one grade of metal, it would naturally be more uniform and regular in quality, which would tend, also, to decrease the cost of manufacture slightly.

In speaking of the relative merits of acid and basic open-hearth

steel, the author states that "the reports of the company's inspectors indicate that the basic steel is not quite so uniform in quality as the acid." During the last two or three years it has been the writer's privilege to spend considerable time in the shops of some of the leading bridge companies, and, in addition to observing closely the various manipulations the metal must undergo before it is finished ready to ship, he has conversed more or less with those who are familiar with the conduct of the metal at every stage of its manufacture. The information gained in this way, added to the results of the testing laboratory, tend to convince him that the product of the acid open-hearth furnace is somewhat superior to that of the basic furnace, notwithstanding the claims of some of the manufacturers to the contrary. Mr. Treadwell.

In the first place it is perfectly rational that acid steel should be better, for it is more homogeneous in its molecular construction. When properly manipulated, it does not require to be recarbonized. Basic steel, however, is first run very low in carbon so as to reduce the amount of the impurities in the metal, and especially to lower the percentage of phosphorus. It is then recarbonized, and to perform that operation so as to obtain a thorough, complete and even distribution of the carbon throughout every particle of 25 tons of metal in one mass is practically impossible. It must be admitted, though, that such a high degree of perfection has been obtained in this direction that it is exceedingly difficult to distinguish the two metals in the ordinary laboratory tests. If a large number of full-size members were tested to destruction, it is possible that the difference would be more noticeable. For instance, in the test to destruction of full-size eye-bars of considerable length, it has been observed that the stretch as measured foot by foot is noticeably more uniform in the case of acid than in that of basic open-hearth steel. This fact alone would seem to prove that the former metal is more homogeneous than the latter.

With respect to the different melts or heats, however, it is believed that basic steel can be made just as regular in quality as the acid product, and possibly more so. The reason for this is the fact that in case of the former, the quality of the metal can be regulated in the furnace by reducing the percentage of the impurities, and then by reintroducing the proper amount of carbon; but in the case of the latter, the quality of the metal depends on the purity of the stock charged into the furnace. In fact, owing to the oxidation of a certain portion of the iron, the percentage of the impurities in the final product is greater than in the original stock or scrap. About the only thing that it is attempted to regulate in the acid furnace is the percentage of carbon, but if it is run too low in the finish and has to be recarbonized, the product is inferior to basic steel. Probably the best quality of acid steel is that made from basic scrap containing small percentages

Mr. Treadwell.

of sulphur and phosphorus, with enough pig iron added to regulate the carbon. In one sense, therefore, acid steel is basic steel refined.

Reasoning along these lines, and not forgetting the results of the testing laboratory, it is difficult to understand how it is possible to produce basic steel superior to or even equal in quality to acid steel, provided the same degree of care and precaution is observed in the manufacture of both metals.

Assuming that acid steel is somewhat better than basic, it is largely a matter of cost whether the difference is great enough to warrant any decided preference being given the former. Acid steel being made principally from selected scrap, its first cost would be considerably increased if there was a large demand for it in preference to basic steel. In view of this fact alone, it is probably more economical in the end to use the basic product, especially if the ultimate strength required is not greater than 65 000 lbs. per square inch. For metal with an ultimate strength above 65 000 lbs. per square inch, the writer would give a decided preference to the acid product.

When it comes to sub-punching and reaming in general, much may be said *pro* and *con*. It is a subject on which there will always be a difference of opinion among engineers and manufacturers. The writer agrees with the author that it is just as essential to ream soft steel and wrought iron as it is to ream medium steel; for, so far as the elastic limit of the metal is affected, one is injured by punching, relatively, about as much as the other. Then, too, it is almost impossible to make long rivets fill punched holes completely, even when the greatest care is taken in heating and driving the rivets. Where the rivets are short, they can be made to fill the holes quite well, if properly heated.

The metal work with the rivet holes punched $\frac{1}{8}$ in. less than the diameter of the cold rivet and reamed to the required size after the several parts have been assembled, or to cast-iron templets, is better than work with the holes punched full size and often badly matched few will deny, but whether it is always better to the extent of the added cost of reaming is a very different question. The writer is in favor of sub-punching and reaming, and particularly so when applied to heavy and important structures, but he does not deem it essential to ream "all metalwork." That high standard of perfection in workmanship might be very desirable, but owing to economic considerations, he believes there is a large class of light work in which it is perfectly allowable and even advisable to omit sub-punching and reaming, at least in those cases where the metal does not exceed $\frac{3}{4}$ in. in thickness, and where the rivets pass through only three or four thicknesses of plate.

It is not practicable to lay down an inflexible rule governing sub-punching and reaming. Each designer will have to depend on his own

judgment in the matter, being guided at the same time by the importance of his structures and the funds at his disposal; but in case of doubt, his decision will always be a safe one if cast in favor of the higher grade of workmanship. Mr. Treadwell.

Probably the most valuable feature of the paper is the illustration, description, and estimate of the weight and cost per lineal foot of each of the thirteen designs worked out by the author. It is interesting to follow the comparison made between the different styles of construction, and to note that the best form, namely, that with braced towers, is the cheapest. One noticeable feature of all the designs is the ample provision of bracing to prevent secondary stresses due to longitudinal and transverse forces. When tower bracing is used, the necessity for fixing the tops of the columns in the direction of the longitudinal axis of the structure is not apparent. Such a fixed condition of the column only augments the temperature stresses without gaining anything in point of strength or rigidity. When the tower bracing cannot be used, however, it is certainly advantageous to fix the columns at both top and bottom.

Another noticeable feature of the author's design is the extension of the columns up to the top of the transverse girders. Whatever may be said against this practice, it certainly has the advantage of greater strength and rigidity. The sections of the columns themselves could hardly be improved upon, at least so far as strength and rigidity are concerned.

CHARLES V. WESTON, Esq.*—The importance of maintaining a high standard in respect to details and workmanship for elevated railroad construction cannot be overestimated, and the writer fully concurs in the author's statement that an elevated railroad structure is just as important as any railroad bridge ever built, because the live loads are frequently applied, and the assumed maximum loads very nearly reached many times each day. The elevated railroad designer should seek to obtain a structure combining the greatest possible rigidity with economic distribution of metal. This cannot be accomplished except by the most careful detailing and excellence of workmanship. Mr. Weston.

Sub-punching and reaming of rivet holes has been rigidly enforced throughout the Northwestern and Union Elevated Railroad work, and the results as indicated in the completed structure have removed from the writer's mind any doubt which may have existed with respect to the advisability of specifying and enforcing sub-punching and reaming for elevated railroad work. Reaming is the only method which will insure an exact coincidence of the rivet holes in the component pieces of the various members of the structure.

The author's statement in regard to the bearing power of Chicago soil seems to the writer to be misleading, and tending to leave the

* Chief Engineer, Northwestern Elevated Railroad.

Mr. Weston. impression that the foundations for the Northwestern and Union Elevated Railroads were designed and constructed for a unit load upon the soil of 1 ton per square foot. The writer has had much experience in excavating and building foundations upon the soil underlying Chicago, and he has seldom encountered, except near the banks of the river, a soil which would not safely support a load of 3 000 to 4 000 lbs. per square foot. At least two-thirds of the Northwestern Elevated Railroad line is located through a sandy district where the soil would safely support loads of 8 tons to 10 tons per square foot. Through this sandy district the foundations were proportioned for unit pressures of 3 500 to 5 000 lbs. per square foot, the actual cost of foundations being greatly reduced below the estimated cost.

Every feature of the detailing of the Northwestern and Union Elevated Railroad structures has been very carefully considered, and the result in respect to rigidity of structure and economic distribution of metal is very satisfactory. If the writer were called upon to participate in the design and construction of another elevated railroad, he would not deviate from the principles which have been followed in the design of the Northwestern and Union roads in Chicago. One detail of these designs he would change, viz., the position of the top chord of the longitudinal girders, with respect to the top chord of the cross-girders. As shown on the drawings, the top chord of the cross-girders projects from 1½ to 3 ins. above the top chord of the longitudinal girders. This detail seriously interferes with the uniform spacing of the track ties, and will increase to some extent the difficulties of renewing the track. Track girders should project at least 1 in. above cross-girders, which insures absolutely uniform spacing of the track ties. When one reflects on this subject it is seen that the entire structure of an elevated railroad, from the foundation to the top chord of the track stringers, is expressly built for the purpose of obtaining a perfect track, and the importance of preparing an absolutely unbroken surface for that track is apparent.

Mr. Lindenthal G. LINDENTHAL, M. Am. Soc. C. E.—Three points occur to the writer in reading the paper. They are in connection with the stairways, station platforms and the æsthetic considerations.

The subject of proper stairways does not fail to impress itself forcibly on every passenger. To the writer's knowledge there is not in this country a single elevated railroad, including the one that the author designed, of which the stairways are proportioned with thought of real comfort in ascending or descending them. The daily blockades in the stations during the rush hours testify to it. The cause for them is plain. The average person, leisurely walking on the level, covers about 30 ins. with each step. To prevent a blockade, that horizontal velocity should be maintained on the stairway during the descent or ascent of about 20 ins., equal to about three stairway steps.

The leg motion for that purpose would have to be three times as fast on the stairway as on the level, involving some athletic skill of which the average passenger is not possessed. Hence the blockade. The proper remedy for it is to make the stairway three times as wide as the passage at the top leading to it, so that the crowd on descending can spread out sideways. The broadest stairway should always be provided for. It should not be more steeply inclined than in the proportion of two horizontal to one vertical. A very convenient proportion is 6½ ins. rise to 13 ins. tread. On all the elevated railroads the stairways are much too steep, and in wet and frosty weather positively dangerous. Mr. Lindenthal

One of the worst examples of badly proportioned stairways was in the first elevated Broad Street Station of the Pennsylvania Railroad in Philadelphia. The first week after completion, so many persons fell down stairs, threatening the railroad company with suits for damages, that it was found necessary to build over the narrow marble steps wooden stairways with less slope and a more convenient proportion of rise to tread. The stairways in the present Broad Street Station are very comfortable and properly proportioned, and good examples of what stairways should be for large crowds.

The separation in the station of the incoming and outgoing passengers is not dwelt upon by the author with sufficient emphasis, although his stations show an attempt to meet that requisite. In nearly all railroad stations and in all elevated railroad stations in the East, the incoming and outgoing passengers are in constant collision. It shows a discreditable want of forethought and study.

Making the trains and tracks noiseless, or nearly so, should be one of the principal concerns of the engineer, whether the law requires it or not. That it must necessarily add to expense, as the author intimates, is a view which the writer does not share.

In mentioning æsthetics in connection with engineering structures, the author touches a subject little appreciated by many engineers. It may be that because the conception of beauty never was and never will be one capable of precise definition, that the engineering mind, accustomed to dealing with concrete matter in precise and scientific ways, has become incapable of judging good architectural appearance in connection with structures. Some engineers' ideas of beauty are running to curves and those of others to straight lines; some claim any structure to be beautiful which is properly proportioned in strength and otherwise well adapted to its utilitarian purpose, and others desire their constructions to be called beautiful, conceived as tools doing their work, and to be classed presumably in the same architectural category with crowbars and wedges. The confusion of ideas of beauty is clearly apparent in what the author says on this point: "the extra cost of decorating an elevated structure is con-

Mr. Lindenthal

siderable," and as proof thereof plans of an elevated railroad of that supposed higher architectural order are shown, in which riveted railing brackets are hidden under ornamental cast-iron consols, resting on air, in which supremely superfluous arches are abutting against slender posts, set off with Moresque caps and pedestals, in which the panels are fitted up with (in such place) meaningless scroll work, and in which lions' heads are impaled on the ends of water spouts. No wonder that projectors of good taste and sense should refuse to grant a dollar for this kind of æsthetics.

It is unfortunately a frequent fact that prominent engineering structures, after having their proportions and lines fixed with the usual inanity and indifference to harmonious and pleasing ensemble, are handed over to some decorator, who is to make it artistically acceptable, according to the amount of money that the owners may be persuaded to spend on so-called æsthetics. There are some such examples in New York, and there are to be more in one or two projected large bridges.

The author should be credited for also saying: "The careful designer can generally manage to make his construction more or less sightly, without adding materially to expense." To which should be added, that it is the essence of the highest engineering skill to give a construction a pleasing appearance and agreeable character, without the addition of unnecessary parts and with the simplest means.

Without skill and thoughtful study a perfect work in that respect cannot be designed. The road to perfection is here, also, from the complicated and unsightly to the simple and æsthetically correct. Intimate knowledge of manufacturing methods is as essential for exercising that skill as freedom from construction and manufacturing bias. For the want of the latter condition, an architecturally meritorious design for an engineering structure may not readily be expected to issue from a manufacturing or contracting establishment.

The author invites criticism as to whether he succeeded in giving the structure for the Northwestern Railroad in Chicago a pleasing appearance. The writer will point out merely for illustration one feature. For every five or six spans there is a braced bent with shallower girders and with stout diagonals to afford longitudinal rigidity. With the technical reasons for this arrangement the writer fully agrees, but the break in the continuity of the beam or girder line at the bent is decidedly unsightly and unnecessary. The observer, except he be a bridge specialist, is not acquainted with, and does not care for, the finesse of bending moments and shearing strains, which prompts the utilitarian engineer to use a shallower girder and to break the continuity of line. It is too unimportant a reason to the beholder, who experiences the disagreeable sensation that something is the matter with the superstructure at that bent. He can readily understand the

purpose and admit the propriety of the bracing every four or five spans, but to his mind uniform strength of the roadway in this structure requires uniform beam height. The unity of appearance is violently interrupted to save a few dollars' worth of iron, which if not saved makes the structure so much stronger and evidently better looking. No amount of cast-iron ornamental brackets and scroll work, put on by a decorating architect, could make up for such fault of the engineer, if a high æsthetical structure, of the kind before mentioned, were to be made of it. Mr. Lindenthal

Another unsightly feature, not difficult to avoid, is the track with the ties sticking out into the air, and giving the structure a ragged and uncouth appearance.

The natural black gray color of iron gives the impression of a strong and serious material, the appearance of which cannot be improved by colored paints. Preserved by oiling and varnishing, the natural color of iron is an essential part of its æsthetical appearance. Dust and rust are easiest discovered on it, and therefore most easily guarded against by timely repairs or reoiling. In rare cases, a colored paint may be more suitable, as for instance in wire cables covered with white paint. They absorb less heat from the sun and appear of larger diameter than with a dark color. Some parts of the New York Central Railroad viaduct on Park Avenue in New York are good examples of simple unadorned iron architecture, although in other respects it is not commendable, as it is atrociously noisy.

In connection with æsthetics in engineering structures it is opportunely interesting to note what the venerable German savant, Prof. Reuleaux, said in his well-known blunt manner in a recent paper* on modern bridge construction.

"I do not regard in proper taste extra ornamentation or attached decorative features, or style subsequently furnished by an architect. By architectural designing, I mean the choice of the principal forms, the disposition of the masses, the arrangement of the lineaments of the structure.

"We are asked to call (*das zweckmaessige*) the suitable or fitting for its purpose beautiful; if this be so, we would have to regard a human skeleton as beautiful, because it is adapted for its purpose in a wonderfully high degree. But it does not give us the sense of beauty; on the contrary, it only fills us with aversion.

"The objection to this criticism might be made that the skeleton has no life, and that it lacks the rounded outlines of living flesh. But if in this respect the suitable to its purpose were always beautiful, then we would have to admit that a Hottentot Venus is beautiful; she is healthy, and she is not lacking in flesh, which we miss on the skeleton, and her build is eminently suitable, in that the dusky mother carries on her posteriors, projecting 30 cms., her youngest offspring, nourishing it at the same time. I doubt very much whether even the defender of the utilitarian will claim beauty for her on that account.

* See *Glaser's Annalen*, February 1st, 1897.

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"We old scholars belonging to the past call that beautiful in a being or in a structure which shows a certain harmonious combination of intellectuality with matter. In that way we have inherited through ages a conception of beauty which is not easily defined by words, but which anyone may appreciate, although he may not be able to create it."

Mr. Pegram.

GEORGE H. PEGRAM, M. Am. Soc. C. E.—The writer agrees with the author that medium steel with reamed holes should be used in preference to soft steel without reaming. Indeed, it would be better to require reaming all punched holes in steel which is to be placed in structures where it will be highly strained or liable to receive blows. If the object is to get fair rivet holes rather than to remove the injured material around the hole, the rigid reamers recommended by the author are, of course, preferable, but the flexible reamers will remove the injured material more uniformly about the axis of the hole, and, the writer believes, will give generally good results.

An elevated railroad structure should be of the best character of bridgework. Elevated roads are always built where the ground is valuable, and proper economy would seem to demand a two-column bent in preference to one of four columns, in order to leave the ground available for other uses as far as possible. This would also apply to braced towers. They no doubt give stiffness to the structure in a much cheaper way than any other, and where the ground can be spared for this purpose it is well to use them; however, experience shows that they are not necessary.

The writer has always believed that cross-ties are out of place on an elevated structure. On the ground, where they are necessary to distribute the weight over the surface, they have proved the best construction, but they are not needed for this purpose on an elevated road, and their effect there is to darken the street below, to intensify the noise, increase the labor of cleaning the structure, and lead to unpleasant drippings after a fall of snow or rain.

The writer submits in Fig. 37 a drawing of the superstructure of the Kansas City elevated road designed by him and built in 1886, in which the rails are carried in iron troughs which also acted as the top chords of the trusses. These channel chords serve also as guard rails, and in case of breakage of a wheel or similar accident, are in effect parallel skids on which the trucks, which should be provided with bolsters located but little above the tops of the channels, might slide. In order to take up as little of the street as possible, the spans were made about 50 ft.; the total weight of steel per lineal foot is 478 lbs. Pin connections were used in this structure, as it is the writer's belief that a structure with much less ugliness and obstruction of light can be built with pin connections. It can be also strengthened with less injury to the remaining parts, and experience has shown that, where properly designed, it is quite as durable. The writer submitted a plan similar to this for the Hoboken elevated road in 1883.

Mr. Pegram.

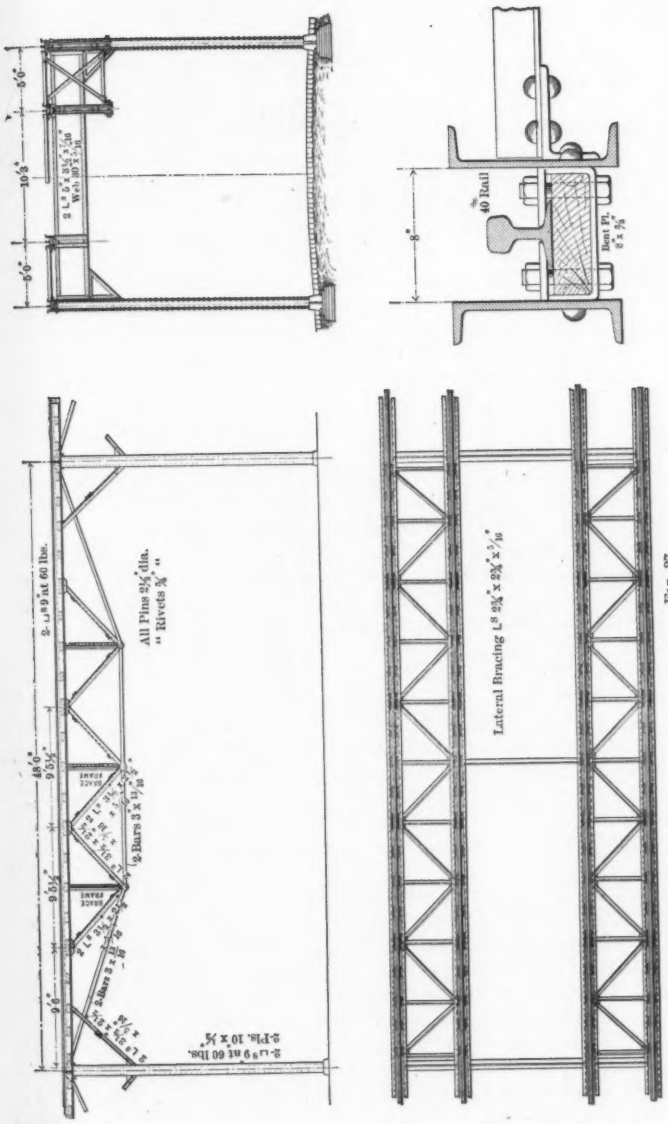


FIG. 37.

Mr. Gates. C. L. GATES, M. Am. Soc. C. E.—Regarding medium versus soft steel, the writer's experience would lead him to prefer soft steel punched over medium steel reamed if the difference in unit stress is assumed at 10 per cent. While it may be right to select medium steel for structures under light traffic, such as that imposed by street railroads, as recommended by the author, the writer does not favor any extensive use of this grade of metal for ordinary railroad traffic except for truss members of long spans which take their maximum stress gradually, and certainly never for short girders subjected to the heavy pounding and vibration of heavy freight trains. The more liberal distribution of metal at a low unit stress seems to be more desirable, and the softer steel more preferable than the more brittle and higher grade of steel; and, if there be any need of reaming at all, by all means let all work be reamed, especially when the thickness of metal exceeds $\frac{3}{4}$ in.

As a matter of economy, there may be a leaning toward medium steel at a high unit stress for structures located at a great distance from the points of manufacturing and center of distribution; but for the Central States, soft steel at a low unit stress will no doubt be used in the future.

Greater care is taken by shop men in matching rivet holes of component pieces of long members, when they know the work is not to be reamed, than when the requirements of specifications call for reamed work. In the former case, if punching is done by piece work the reaming over of misfits has to be done by and at the expense of shop men, and thus they find it to their interest to do good work. With the multiple punch and spacing table very accurate work is done in the shop the writer is connected with, so reaming can generally be dispensed with, notwithstanding the assertion of the author to the contrary.

In this connection, the writer would assert the prediction that for the bridge structure of the future, if not of to-day, good specifications will require that every piece of soft or medium structural steel, and certainly all subject to tension in the finished member, shall be thoroughly and uniformly annealed after the process of straightening and punching has been completed and before riveting is done, for obvious reasons.

As regards the use of basic open-hearth versus acid open-hearth steel, it would be profitable for the profession to hear from the steel-maker direct on this subject. While some inspectors are inclined toward a preference for acid open-hearth steel, owing to the apparent higher elastic limit, yet it must be admitted that in accepting acid steel a minimum of 0.08% of phosphorus must be conceded, while for basic steel it is safe to specify as low as 0.05% for phosphorus, and one can generally rely on obtaining as little as 0.02% or 0.03 per cent. Phosphorus being known as the great enemy of good steel, especially in

cold climates or where it is subject to sudden changes to very low temperature, this fact alone, in the writer's opinion, should lead to the more general preference of basic open-hearth steel, more particularly when the market price of the product is taken into consideration. Mr. Gates.

Referring again to design, the author has certainly shown a happy solution in solving in an economical manner the problem of bringing wind stress or train vibration to the trestle posts, thus relieving the generally much-abused end beam from excessive longitudinal bending strain. The writer does not agree, however, with the author's preference for the four-post bent for a four-track railway. All bents of an elevated railway must necessarily be an obstruction to the established street traffic at the lower or ground grade, and a four-post bent certainly offers more serious objections on that account than a two-post bent; this is slightly intensified when first cost is in favor of the two-post bent. Another objection to the use of a four-post bent is that the foundations of the four pedestals are liable to different settlements under load, thus causing ambiguous stress in the main beam, for which this member is not generally proportioned.

A. T. Tomlinson, M. Am. Soc. C. E.—The author has evidently given much thought and study to the several designs for elevated railway structure discussed in his paper. The design adopted was chosen entirely on account of its superior rigidity, adaptability to the different conditions to be met and æsthetic effect, and without regard to the difficulties which would arise in laying, and later on, in maintaining, the track. Mr. Tomlinson.

In the designs chosen for both four-track and two-track structure, the transverse girders project above the longitudinal stringers from $\frac{3}{4}$ in. in the double-track to 3 ins. in the four-track. This is not a material objection on straight track, but it will be readily seen that on curves where it is generally impossible to set all the transverse girders radially, and where frequently some of the transverse girders make very acute angles with the center line of the track, the conditions are bad. The ties must be laid parallel to the transverse girder, or if laid radially, they will have to be fitted over the transverse girder, materially damaging the tie and rendering replacement very difficult.

The author's original specifications called for 6 x 8-in. ties laid flat and spaced 14 ins. center to center. This was changed on the first track laid on Lake Street from Market Street to Wabash Avenue, to 15 ins. center to center, in order to bring the ties out even at rail joints. This track was laid without tie-plates. After the adoption of the Servis tie-plate, the spacing was increased to 18 ins. on straight track, retaining the 15-in. spacing on curves and cross-overs.

The objection to wide spacing of ties, and the author's reason for specifying 14-in. spacing, is that in case of a derailment there is a strong tendency for the ties to bunch. This, in the writer's opinion,

Mr. Tomlinson. is not a valid objection, as the ties are firmly bolted to the longitudinal stringers, and each tie is securely bolted to two of the four guard rails, to the inside and outside guards alternately. Many elevated railroad accidents have come under the writer's observation, but in none of them has he known the ties to bunch.

By spacing 18 ins. instead of 14 ins., a saving of 22¼% is made in ties, tie-plates, spikes, bolts, washers, etc., which is no inconsiderable item, being at least $1 000 per mile of single track for ties alone, and probably $1 000 more per mile for fittings and labor of laying track, to say nothing of the eventual cost of replacement.

The lumber used in the track is long-leaf southern yellow pine, vulcanized. The writer thinks a mistake was made in specifying that absolutely no sap would be allowed. In the first place, if 1 in. of sap wood had been allowed on two corners of the ties, guard-rails and heavier joists, the cost would have been reduced, but more important than this, is the fact that in almost every piece of dimension lumber, the heart of the tree and center of stick are generally coincident; consequently, whichever side is laid downward, the upper side checks badly. Had a small amount of sap been allowed, the heart side could always have been laid downward, and splitting on account of weather have been reduced to a minimum.

The author originally specified an 80-lb. rail in which the metal was distributed as follows: Head, 47%; web, 20%; flange, 33 per cent. The rail finally adopted was one which was already standard on the Lake Street Elevated Railroad, and known as No. 8001 in the Illinois Steel Company's book of rail sections. This section varies but slightly from the standard 80-lb. rail, designed by a committee of the Society, and having the metal distributed as follows: head, 42%; web, 21%; flange, 37 per cent.

In the track now being laid on the Union Elevated Railroad, and to be laid on the Northwestern Elevated Railroad, 60-ft. rail will be used, connected by Weber rail joints, using four ¾-in. Harvey grip bolts, the joints suspended and breaking even, except on curves, where the joint of one rail is placed as nearly as possible opposite the center of the other rail.

Mr. Rowe. SAMUEL M. ROWE, M. Am. Soc. C. E.—The Northwestern Elevated Railroad Company directed experiments to be made to test various paints as to their relative ability to protect metalwork against atmospheric action, and particularly against the gases produced by the combustion of coal, with which the atmosphere of the city is more or less pervaded. Each paint was tested by applying it to four steel plates, three coats on each plate. Some of these were exposed to smoke and steam from locomotives, and others to the smoke of bituminous coal in a box prepared for that purpose. Neither of these methods were carried on long enough to furnish decisive results, but the condition

of plates exposed to the atmosphere was observed at intervals during a period of two years. Mr. Rowe.

The dark mineral paints were found to retain their color best, the effect of the weather on the oils being less than where lead and zinc were used as pigments. The use of graphite with white lead and zinc apparently gives the most permanent light shade.

In determining the adhesion of paint to metal, a toothed chisel was found advantageous. The blade is $\frac{3}{4}$ in. wide, one-half toothed with $\frac{1}{32}$-in. notches, $\frac{1}{16}$ in. apart, and the other half with $\frac{1}{64}$-in. notches, $\frac{1}{32}$ in. apart. If the paint is loose or easily parted from the metal, this will be at once manifested if it is attempted to shave a strip of the paint from the metal; the surface of the latter will be free from paint and show any rust spots which may have formed in consequence of the damaged condition of the covering. If the paint is very brittle, the whole surface will be stripped clean, whereas if it is tough, elastic, and clinging closely to the metal, each notch in the tool will leave a fine, continuous line of paint.

The durability of paint and the thoroughness of the protection it affords to the metal depend largely on the resistance of the surface and body of the paint to the action of the weather. If the surface changes or loses its density, the body of the paint will soon do the same, and the whole become porous, absorbing moisture and opening a way for rust. The best degree of elasticity and toughness in the paint seems to be that which will prevent breaking or checking by alternations of the temperature to which it is exposed and from the usage to which it is subject. A tough, elastic paint will roll before the tool and form a wad which will feel like soft leather when rolled between the thumb and finger. A hard, brittle paint will crumble into dust.

Some of the paints tested were soft and sticky when exposed to a summer temperature after the lapse of two years, a condition undesirable in any paint except one exposed to a combination of locomotive steam and smoke, one of the most destructive agents to be withstood. Some of the Chicago viaducts suffer severely from this action, the metal of the lower chord and floor systems being eaten away so rapidly as to require the renewal of these parts long before the less exposed portions of the structure are affected materially. In such cases anything that will withstand the action of the gases on the metal is invaluable. Neither time nor means were available to analyze these paints to determine the cause of the different results, but it has been suggested that the use of animal fats with the oils may produce the softness mentioned, while insoluble or very refractory gums of some kind may help to produce toughness and firmness, when combined with linseed oil.

The asphaltum paints harden like glass forming a surface which seems to resist the action of the coal gases perfectly, but they are liable

Mr. Rowe. to check and do not cling to the metal, being easily broken and separated from it. The Eureka paint used by the author on the Wabash Extension structure covers and clings well to the metal, holding its color fairly, but when shaved with the testing chisel, it is hard and brittle, and seems to some extent porous and likely to absorb moisture.

The author's suggestion to give one coat of linseed oil to all work before it leaves the shop is a good one, and a complete immersion of each piece after it was thoroughly cleaned would be still better. By this means parts would be reached which will be inaccessible for painting afterwards.*

The question of the bearing qualities of the soils in Chicago, with reference to foundations for an elevated railroad, is one that requires investigation somewhat in detail, as there is a great variation in its character in the different parts of the city. That district traversed by the Union Loop, Wabash Extension, South Side Rapid Transit and part of the Northwestern elevated lines, consists of sand, gravel, or both in varying quantities, while part of the Northwestern elevated and almost the entire extent of the Lake Street elevated lines cross a section where the underlying formation on which the piers rest is a plastic clay.

The country on which Chicago is built is almost as level as the lake itself, and only 6 to 15 ft. higher. At the level of the pier foundation, it is almost invariably saturated with water. The presence of water pipes and the slight settlement of elevated structure foundations on them have been found to contribute still further to the difficulties encountered. Where sand and gravel are found, the presence of the water does not materially affect their bearing qualities; but in the clay, failure in many cases is complete, the pier being sustained by the adjacent structure and swinging like a pendulum, distorting and tearing the plates and riveting of the structure.

In consequence of the early failure of many of the pier foundations on the Lake Street elevated line some tests were made. The general practice seems to have been to make the base of the pier about 7 ft. square, equal to 49 sq. ft., giving a pressure of about 20 lbs. per inch. The testing appliance consists of a square wooden block or foot piece laid upon the soil to be pressed, its upper surface being armed with a cast-iron plate with a socket to receive the pivot of a post on which the loading is placed; and a post provided with cross-arms and a platform to receive the loading, and a pin and guys at the top to hold it in a vertical position. The loading consists of pig iron, the pieces of which weigh as nearly as may be 80 lbs. each, to facilitate the estimate of the amount of loading. The compression from

* Mr. Rowe has tabulated the results of his tests of paints of various brands in a statement which is on file in the Library of the Society.

the loading is taken with an engineer's level, the rod being placed on the cross-arms, and readings noted at each addition to the loading. Mr. Rowe.

There were but three tests made, and these were secured only by persistency on the part of the consulting engineer.

In the first test the clay was tested at a depth of about 7 ft. below street grade or 5½ ft. below the original surface. The clay was in its original condition, and was a plastic yellow mass mottled with a blue or slate color, and wet to full saturation. The wooden foot plate was 18 ins. square.

The following is a synopsis of the results:

Load.	Load per square inch.	Compression each loading.	Total compression.
1 500 lbs.	4.6 lbs.	0.000 ft.	0.000 ft.
3 500 "	10.8 "	0.009 "	0.009 "
5 500 "	17.0 "	0.008 "	0.017 "
7 500 "	23.1 "	0.018 "	0.035 "
9 500 "	29.3 "	0.018 "	0.053 "
11 500 "	35.5 "	0.052 "	0.105 "
12 000 failed by sliding cornerwise.			

The second test, also in clay, under similar circumstances, except that a foot piece 2 ft. square was used, gave the following results:

Loading.	Load per square inch.	Compression each loading.	Total compression.
1 500 lbs.	2.6 lbs.	0.000 ft.	0.000 ft.
3 500 "	6.1 "	0.027 "	0.027 "
5 500 "	9.5 "	0.001 "	0.028 "
8 200 "	14.2 "	0.005 "	0.033 "
9 500 "	16.5 "	0.004 "	0.037 "
11 500 "	20.0 "	0.002 "	0.039 "
13 500 "	23.4 "	0.004 "	0.043 "
15 500 "	26.9 "	0.007 "	0.050 "
17 500 "	30.2 "	0.011 "	0.061 "
19 500 "	33.7 "	0.013 "	0.074 "
21 500 "	37.2 "	0.019 "	0.093 "
23 500 "	40.8 "	0.029 "	0.122 "
25 500 "	44.2 to complete failure, the block tipping slightly cornerwise as before.		

The third test on the Wabash Extension was made in the bottom of a pier foundation pit at about 1 ft. below the original ground surface, the soil being an extremely fine, clean sand, the depth of which was not ascertained, but assumed to be several feet, the sand being so exceedingly fine as to be taken for clay at first sight.

Mr. Rowe.

The foot block used was the same as in the second test.

Loading.	Load per square inch.	Compression each loading.	Total compression.
1 500 lbs.	2.6 lbs.	0.000 ft.	0.000 ft.
7 500 "	13.0 "	0.003 "	0.003 "
9 500 "	16.5 "	0.003 "	0.006 "
11 500 "	20.0 "	0.003 "	0.009 "
13 500 "	23.4 "	0.003 "	0.012 "
15 500 "	29.9 "	0.003 "	0.015 "
17 500 "	30.2 "	0.003 "	0.018 "
19 500 "	33.7 "	0.003 "	0.021 "
21 500 "	37.2 "	0.003 "	0.024 "
23 500 "	40.8 "	0.003 "	0.027 "
25 500 "	44.2 "	0.004 "	0.031 "
27 500 "	47.8 "	0.005 "	0.036 "
29 500 "	51.2 "	0.005 "	0.041 "

It will be seen that in the first two cases the compression was accelerated at about 20 lbs. to the square inch, and in the third case at about 40 lbs. In the case of the first two tests 20 lbs. is the pressure at which the clay begins to flow, and may be safely called its ultimate bearing strength under a static loading. In the third test, however, the flowing could hardly have commenced at the point of acceleration, but it must have been due to a softer, less stable stratum a few feet below. Hesitancy to incur any further expense in this investigation prevented any examination of this subject.

Loading at 20 lbs. per square inch is probably entirely safe in sand like that of the third test, and in sand and gravel, but on clay, with a base of the same area, there have been cases of complete failure, just as the tests indicate as probable, the column with the pier attached swinging, and being supported only by the adjacent columns, as before stated. The static load carried by each column is about 150 000 lbs., including the weight of the cars in the train, not taking into consideration the disturbing elements caused by the impact of rapidly running trains and of the tremor produced by the action of the brakes, the effect of which is difficult to estimate, but evidently of very much importance. The last two causes are the main sources of failure, as the vibrations from the structure are transmitted by means of the column to the pier and whatever movement reaches the clay upon which the pier rests very quickly affects its bearing qualities, for in its saturated state it becomes a semi-fluid very quickly. That this is due largely to impact seems apparent when it is stated that failure first manifests itself between stations where the speed is greatest. The writer thinks this kind of foundation should not be trusted beyond 10 lbs. per square inch under the existing conditions, and even then the

pier should be massive enough to take up the tremor largely by its inertia. If the pier is too light for this, the interposition of 2 or 3 ft. of broken stone between the base of the pier and the clay might be effective and economical. Mr. Rowe.

J. A. L. WADDELL, M. Am. Soc. C. E.—*Medium Steel versus Soft Steel.*—A comparison of opinion on this subject expressed in the discussion shows quite a diversity of ideas, with the preponderance in favor of medium steel. Those who advocate the use of soft steel do so because of one or both of two claims, viz., first, when soft steel is adopted, reaming may be dispensed with; and, second, soft steel is safer than medium steel on account of its greater uniformity and less liability to crack. These claims do not hold, for the reaming of every quality of steel or wrought iron is necessary, not only to remove the injured material, but also to ensure proper matching of rivet holes, and the greater uniformity of soft steel as compared with first-class medium steel is problematical. It seems from the discussions that there should be a slight difference in the ultimate strength of acid and basic steel, as suggested in the paper. Mr. Treadwell strikes the keynote to this question when he points out that the limits of soft and medium steel overlap to such an extent that manufacturers often make the same quality of metal answer for both classes, and when he suggests a compromise in the classification to suit the various manufacturers of structural steel. For such a compromise the author would suggest the following: Soft steel, 50 000 to 58 000 lbs.; medium steel, 58 000 to 66 000 lbs.; high steel, 66 000 to 74 000 lbs. Mr. Waddell.

With this classification soft steel should be used for rivets and adjustable members only, medium steel for all other portions of all viaducts, elevated railroads, bridges of ordinary span lengths, and the floor systems and lateral systems of long-span bridges, and high steel for the main truss members and pins of long-span bridges.

It is evident that basic open-hearth steel has come to stay, and that it will be used ordinarily in preference to acid open-hearth steel on account of its slightly lower cost. It appears also that the best results are not attained with the basic product by demanding an average ultimate strength as high as 64 000 lbs.; consequently, the proper thing to do is to lower the ultimate requirement to suit the manufacturers of basic steel. From the author's experience during the last three years, he would consider that a range in ultimate strength from 58 000 to 66 000 lbs. would suit very well for basic open-hearth steel as at present manufactured. The soft steel, of course, would also be manufactured by the basic open-hearth process, but the high steel should preferably be made by the acid open-hearth process.

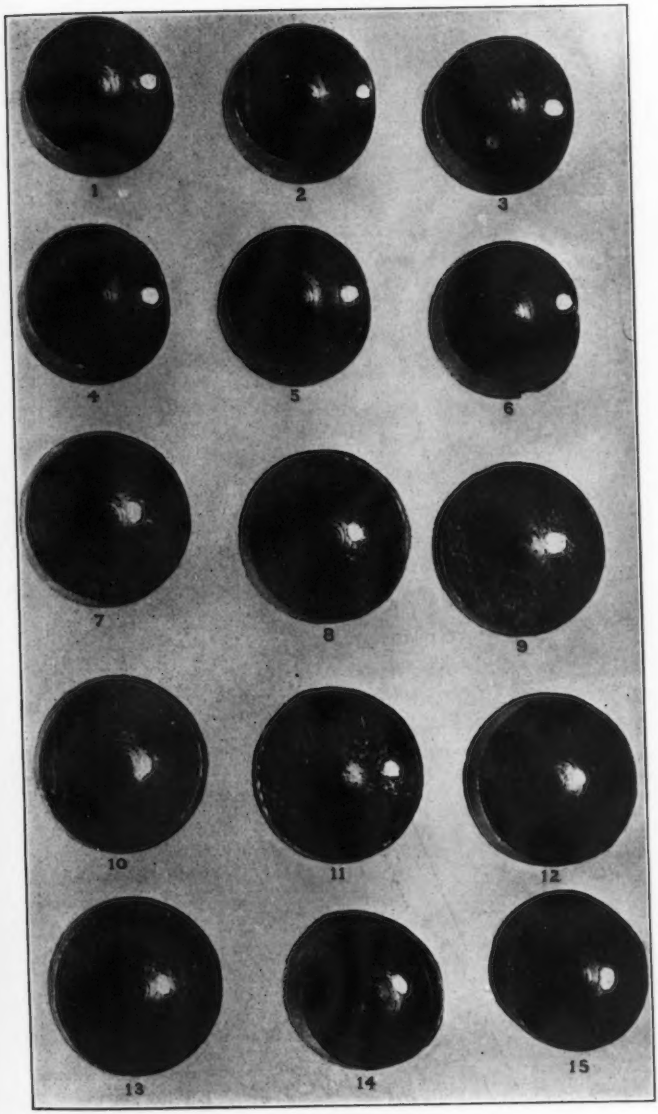
Sub-Punching and Reaming.—A comparison of the opinions on this subject expressed in the discussion shows considerable diversity, with the preponderance in favor thereof. Some claim that accurate work

Mr. Waddell. and properly matched rivet holes are attainable without sub-punching. Such has, unfortunately, not been the author's experience hitherto, for he has had a great deal of trouble from badly matching holes in the field whenever the sub-punching was not called for.

Anticipating claims in the discussion that rivet holes will match properly without sub-punching, the author a short time ago requested his chief inspector to procure for him from a certain prominent bridge shop, where some of his work was then being manufactured, a couple of dozen specimens of punchings showing by the template center marks variations from correct location. Plate XI is engraved from a natural scale photograph of fifteen of these punchings, the proper centers being indicated by the white spots, which were marked on the punchings by rubbing chalk into the template center holes.

The showing made by these specimens is most discouraging to those who hope to obtain good shop work, either by simple punching or by sub-punching and reaming. It took the inspector only about a minute apiece to find these eccentric specimens, which shows that badly matched holes at this shop are by no means uncommon, and confirms the author's opinion formed by previous experience with work from the same shop. The cause of such great eccentricity is certainly the objectionable piece-work system mentioned in Mr. Stowell's discussion. In the author's opinion, piece-work in bridge shops should be discouraged in specifications for structural steel-work. Fortunately, though, such a bad showing as that given on Plate XI would not be made by more than one or two of the large bridge manufactories, although Mr. Horton says in his discussion that $\frac{1}{8}$-in. eccentricities in punched work are of common occurrence. The author's experience with two of the manufacturing companies on the Union Loop and Northwestern Elevated lines leads him to the conclusion that punching can be done with a general limiting variation of $\frac{1}{16}$ in. To illustrate the effects of variations of $\frac{1}{16}$ and $\frac{1}{8}$ in. for both sub-punching and full-size punching, the author has prepared the drawings shown in Fig. 38. They give the worst possible combinations of eccentric holes for two, three and four pieces of metal connected by $\frac{7}{8}$-in. rivets. It is evident from these diagrams that if the limit of $\frac{1}{16}$-in. variation be adhered to, and if the work be sub-punched and reamed, there will be no irregular holes to fill by the rivets. If the holes be punched full size, the resultant holes will often be quite irregular and probably often not completely filled. If the limit of $\frac{1}{8}$ in. be permitted, the reaming will make the holes nearly true circles, and small enough to be completely filled by the rivets, but when the holes are punched full size, the irregularity will often be so great that the rivets cannot fill the holes.

In the author's opinion, inspectors ought to hold down the shops to a general limit of variation in punching of $\frac{1}{16}$ in., passing occa-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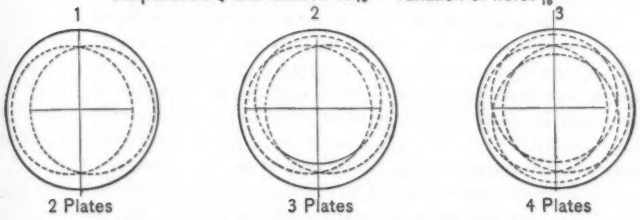
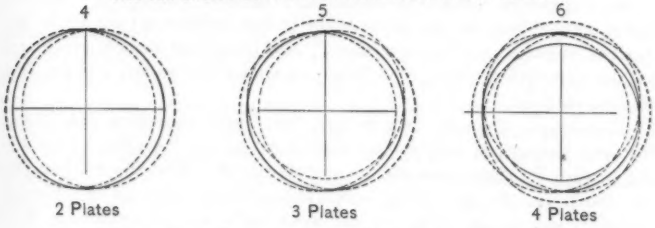
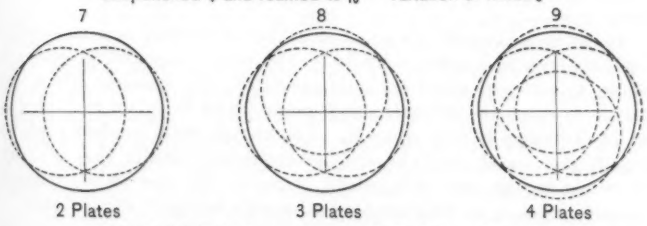
Subpunched $\frac{3}{4}''$ and reamed to $\frac{15}{16}''$ Variation of holes $\frac{1}{16}''$



Punched full size but not reamed. Variation of holes $\frac{1}{16}''$
The full circles denote the true location of the holes.



Subpunched $\frac{3}{4}''$ and reamed to $\frac{15}{16}''$ Variation of holes $\frac{1}{8}''$



Punched full size but not reamed. Variation of holes $\frac{1}{8}''$
The full circles denote the true location of the holes.

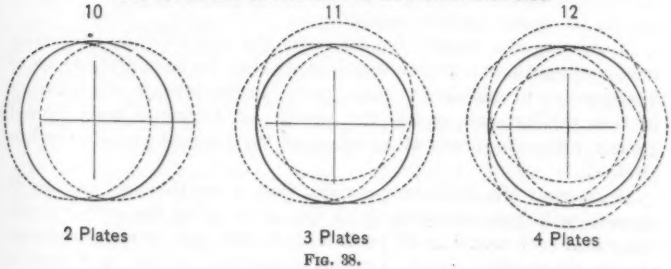


FIG. 38.

Mr. Waddell. sionally a few variations between $\frac{1}{16}$ and $\frac{1}{8}$ in., and rejecting any piece where there is a variation exceeding $\frac{1}{8}$ in.

Some one may remark that, if such variations as those just mentioned be permitted, the metal injured by the process of punching will not all be removed by the reaming; but it must be remembered that it is only an occasional hole in good shop work that will vary as much as $\frac{1}{8}$ in. from correct location, that not more than one-fourth of the holes will vary over $\frac{1}{16}$ in., and that most of the combinations of eccentricities shown in Fig. 38 will be, to say the least, unusual.

The author's experience on the Chicago elevated railroads has confirmed him, as the same experience has convinced Mr. Weston, the chief engineer, in the opinion that, except solid drilling, which as yet is too expensive, "reaming is the only method which will ensure an exact coincidence of the rivet holes in the component pieces of the various members of the structure"; and there has been nothing said in the discussion which even tends to shake the author's conviction on this subject.

Cement and Concrete.—Answering Mr. Hall's question concerning fineness, the author would state that there was no intention of excluding foreign Portland cements by specifying that 90% should pass the No. 100 sieve. In fact, there was a considerable amount of a foreign cement used at one time on the work; this was an extremely fine-ground cement and a very superior article, if not too old or damaged when used.

It has been the author's practice up to the present time to specify both superior and inferior limits for the tensile strength of cements owing to a notion, which formerly prevailed, that a cement which develops its strength slowly is much more likely to retain it than one which develops it very quickly. The author must confess that he is still prejudiced this way, but acknowledges readily that he may be wrong in the case of Portland cements. In case of the natural cements, though, he feels confident that this notion is about right.

For field practice, the author does not specify the temperatures of the air and water, as these cannot always be regulated conveniently, but for laboratory tests he would do so.

Answering Mr. Stuart's remark about the wide latitude allowed for tensile strength, the author would reply that his specifications are so drawn as not to exclude any really good cement because of a tendency to slow setting, and, again, the results of briquette tests depend greatly upon the personal equation of the man who made the briquettes.

Answering Mr. Belknap's remark, that a one-three-six mixture of concrete will have all the voids in the stone filled, the author would reply that such would in all probability be the case, were the concrete always thoroughly mixed, but his experience proves that such a

mixture often shows numerous voids. On this account, as stated in the paper, he prefers to use for bridge piers a one-three-five mixture for concrete deposited in the air, and a one-two-four mixture for concrete deposited under water. Mr. Waddell.

The author certainly never intended to recommend an "eminently slow-setting cement" for concrete to be deposited under water. Mr. Belknap does not recognize the fact that none of the cement for the Chicago elevated railroads was to be used in that way.

Paint.—It is to be regretted that the paper has brought out so little discussion concerning the painting of metalwork. However, Mr. Rowe's investigations are valuable as far as they go, but they are unfinished.

It is often amusing to hear the conflicting opinions of even well-informed engineers concerning the paint question. Some say that the oil is everything and that any kind of a pigment will do, while others say that the pigment is the sole protective agent and the oil only a solvent. Some condemn *in toto* the use of thinners, while others say that they improve the paint and add to its life. Some say that red lead is the only proper paint to use, while others claim that it is inferior to iron oxide paints. Some think that the last-named pigments make the best possible paints, while others say that they are merely iron rust, and that their use is simply an invitation for rust to develop. Some say that patent mixtures and secret process paints are all humbug, while others pin their faith to some especial mixture or mixtures, or to some real or fancied manipulation of known or unknown ingredients. In short, the engineering profession is all at sea on the paint question, and is likely to remain there until some organized investigation is made. In the author's opinion, the subject is one of sufficient importance to warrant the appointment of a special committee of the Society to experiment and investigate on the subject for a term of several years until valid conclusions can be reached.

The author's idea of coating the metal with oil before it leaves the shelter of the roof of the rolling mill is to prevent rust from forming while the metal is in transit to the shops or stored outside of the latter waiting to be manufactured. This method would certainly give the mill people some extra trouble, but that could be paid for. It is claimed, and perhaps justly, that the greasy surface of the oiled metal gives trouble in laying off the work in the shops, and that on this account a coat of carbon primer at the mills is preferable.

The author's preference for Eureka paint was due primarily to the high recommendation given it by A. P. Boller, M. Am. Soc. C. E., and afterwards to the results of Mr. Rowe's preliminary experiments. Mr. Rowe found, however, several other paints that stood his tests as well as did the Eureka.

One objection to a coat of oil alone at the shops after manufacture

Mr. Waddell. is that when the metal is shipped, there is often no certainty as to how soon it will receive its first coat of paint. The author has often noticed metalwork badly rusted because it was only oiled at the shops and because its erection was delayed. The shipping of metalwork covered with undried paint, as mentioned by Mr. Boller, is a very reprehensible practice, and should be prohibited in standard specifications for structural metalwork.

The great uncertainty on the paint question is due to a number of causes, the principal of which are the following:

Permitting rust to form on the metal before the first coat of paint is applied.

Applying the first coat improperly, covering metal from which mud, ice, grease, etc., have not been removed.

Adopting cheap paints from false notions of economy.

Dishonest practices on the part of the manufacturer or mixer of the paint.

Carelessness in mixing paint, and neglecting to keep heavy paints properly stirred.

Slovenliness in applying the paint to the metal.

Using paint that has stood in pots over night and has deteriorated thereby.

Neglecting too long to repaint, and thus allowing rusting to set in.

The requisites for an ideal metal paint are the following:

Thinness, so that it can be applied readily, and so that it will cover a comparatively large surface per gallon.

Lightness of the solid particles, so that there will be no settlement in the bottom of the paint pot.

Great and close adhesiveness to the metal.

Quickness in drying.

Absence of blisters in both fresh and old painted surfaces.

Ability to receive well and retain closely one or more additional coats of paints of the same kind or of other kinds.

Durability.

Cheapness in first cost.

The man who will invent a paint that will fill all eight of these requirements, and who can demonstrate to engineers that he has done so, can certainly make a fortune out of his invention.

Four-Column versus Two-Column Structures.—Several engineers appear to disagree with the author in his preference for the four-column structure. He was influenced in his decision principally by the following reasons:

The cantilevering of an entire track beyond a column is rather awkward construction and causes reversing stresses in the cross-girder.

Mr. Waddell.

The thrust from braked trains can be more readily taken care of with four columns than it can with two.

The four-column structure will prove more rigid than the two-column structure.

Mr. Pratt's objection to the four-column structure on account of the possibility of the settlement of foundations is not a valid one, for properly designed and built foundations will never settle. If a single settlement of a pedestal on either of the author's Chicago lines of elevated railroad ever occurs, it will be a matter of great surprise to him, although he is not responsible for the sizes of the concrete pedestals, as Mr. Weston varied them to suit the different conditions as they developed. However, Mr. Weston has always tried to err upon the side of safety on this question of foundations, owing to the expensive experience he has had in repairing the faulty work on the old portion of the Lake Street Elevated, which was built before he was chief engineer.

Mr. Pratt's unfortunate experience with pedestal foundations may be due to a softer stratum of material underlying the gravel, or perhaps to the fact that it is within the realms of possibility to double the pressure on one side of a pedestal foundation by the thrust of a braked train.

As the author has designed the metalwork on the Northwestern Elevated, a settlement of one pedestal in a bent would be less injurious to it in the case of the four-column structure than it would be in the case of the two-column structure.

Mr. Gates' objection to the four-column structure, because of obstruction to traffic, will not hold, as this class of construction is used only on the company's private property, where no traffic exists.

Braced Towers versus Solitary Columns.—The author's braced tower design appears to have met with general approval from those discussing the paper, although Mr. Smith dissents therefrom, stating that the thrust from braked trains "is not conveyed, to any extent, to the columns," and that "no bending can be produced upon the columns, for it is counteracted by the deck."

These statements are certainly incorrect, for no one will deny that there is a great thrust exerted by stopping in the shortest possible distance, with the air brakes, a train moving at a velocity of 40 miles per hour, and that this thrust must eventually reach the ground. If there be longitudinal sway bracing like that adopted for the Northwestern Elevated, the thrust will travel by that; but, if not, it must go by way of the columns and produce bending thereon.

It is true that the continuity of the deck tends to distribute this thrust over a number of columns, but the extent to which this distribution takes place is a matter of surmise. Some engineers appear to forget that when a light column carrying a vertical load is deflected

Mr. Waddell. from the vertical by a thrust, it is subjected to two bending moments, viz., that due to the thrust itself and that due to the vertical load, the lever arm for which is the total deflection. The column has therefore to withstand the combination of these two moments and the vertical load. Mr. Smith says that the thrust upon one track is distributed over the other three. He forgets that two trains on contiguous tracks will often approach a station at the same instant, running in the same direction, with the brakes set. If at the same time there be a train or two trains starting on the other tracks, all three or four thrusts will be in the same direction. Mr. Smith talks of setting the structure in motion before any bending of columns can occur. He would reduce the question to one of dynamics, while it is, upon the face of it, simply one of statics. He says:

"Were it possible to design a column section in any case which would carry the load due to compression, without longitudinal strength, then some metal might, in this case, be necessary to withstand any light stress caused by thrust. This being impossible, however, the conclusion is drawn that any metal used in any part of a structure to withstand horizontal thrust in a longitudinal direction is superfluous and needless expense."

This is a bold statement by Mr. Smith, and probably he is the first to express it so plainly, although some such erroneous notion must have existed in the minds of the designers of most of the older elevated railroads.

Mr. Campbell's experience on the Sioux City Elevated, where the effects of both longitudinal and transverse thrusts on the columns were entirely ignored, is pretty conclusive as to the necessity of giving due consideration to horizontal loads. As Mr. Campbell states, the vibration of the structure "was plainly noticeable at a point 2 000 ft. away from the moving train." The author has been told that during erection long portions of this structure moved as much as 2 ins. longitudinally and had to be moved back by jack-screws. In this work the columns were proportioned for the effects of live and dead loads only, as Mr. Smith would advise.

To illustrate the necessity for taking care of longitudinal thrust and traction of trains, the author herewith reproduces extracts from a letter concerning the paper from H. G. Kelley, M. Am. Soc. C. E.:

"Many of the points involved are of special importance, and if accepted as correct will require a radical departure on certain lines from the present methods of design:

"The point to which my attention has been especially directed by reading your paper is the resultant of the traction force exerted by engines, and the effect of such resultant upon structures, due to the passage of engines and trains. The mathematical principles involved will no doubt be brought forth in the published discussions, and while your assumption that 20% of the greatest live load between two adjacent expansion points will act as a horizontal thrust may not be entirely agreed to, nevertheless experience has shown that a consider-

able allowance should be made and provided for; therefore any facts obtained by actual experience in construction and maintenance will assist materially in arriving at a true conclusion, and in this consideration wooden trestle-work, which constitutes a large portion of the bridging of this country, should not be excluded, for it presents valuable information concerning structures in which theoretical considerations are usually excluded, and details to take up or reduce longitudinal vibrations are seldom constructed. Mr. Waddell.

"I will therefore present one case coming under my own observation, and in fact under my charge, which is an especially valuable one, showing, as it does, that a longitudinal vibration is transmitted through

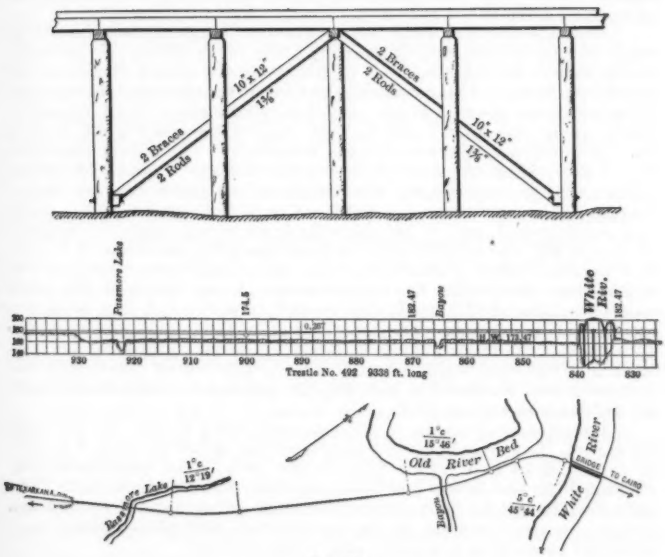


FIG. 39.

elevated structures for surprising distances. The structure is a wooden trestle, upon the line of the St. Louis Southwestern Railway. This trestle was constructed of pile bents, with panels of 13 ft. 8 ins.; each bent contained four piles, except in the deepest portions, where five piles were used to the bent; the piling was of oak and red cypress, with specifications calling for not less than 10 ins. of heart at the point; the deck was composed as follows:

"Caps.....	12 x 12 ins.,		12 ft.	long.
"Stringers....	6 x 14	"	14 "	long, 3 ply on each side.
"Ties	6 x 8	"	9 "	long, with 12 ties to the panel.
"Guard rails..	6 x 8	"	16 "	long, notched down 1 in. over the ties, and bolted to every fourth tie.

Mr. Waddell. "Every cap was drift-bolted to each pile under it, and each chord of stringers was drift-bolted to the caps.

"Upon examination of the drawing (Fig. 39), which I enclose, you will note that the trestle varies from 10 to 30 ft. in height, and has a total unbroken length of 9 338 ft., with three curves in its length.

"Upon assuming charge of the bridge department of the above-mentioned road several years ago, it became necessary to make a personal examination of the various structures, and I have selected the case of trestle 492 as one out of several trestles of unusual length where the same results were noticed. My first inspection of this trestle showed a visible longitudinal variation of such extent, under the passage of trains, that a careful investigation was made to determine the extent and force of the thrust.

"To make the following facts perfectly clear, reference should be made to the accompanying drawing (Fig. 39). From this you will notice that at its north end the trestle connects with a bridge across the White River. This bridge at the time of the observation consisted of an iron draw span of 355 ft., and two combination Pratt trusses of 125 ft. each, one span being at each end of the draw span; both of these combination spans were upon falsework. The observations disclosed that, when any north-bound train, even at a speed of but 12 miles an hour, rolled upon the trestle at its extreme south end, a longitudinal vibration was transmitted in a few seconds to the north end of the trestle, and by the time the train would reach the tangent, at station 902, the vibration at the span reached a maximum of 1½ ins., this impulse being conducted to the span itself and vibrating it in unison with the trestle, the measurements being taken at the point where the rails of the fixed span rested upon the end floor beam rail rests of the draw span. The construction of the trestle precluded the opinion that the vibration was confined to the deck alone, for the drift bolting to the caps made it certain that a portion of the thrust was communicated through the piling to the ground, causing the piling to act as beams as well as posts.

"I at once had constructed a system of struts to take up or reduce the thrust, the general plan of which is shown on the drawing (Fig. 39). It consisted of two yellow pine beams, 10 x 12 ins. in cross-section, running from the cap on one bent to a brace timber at the foot of the piling on the second bent each way from the first one; and in addition to this, iron tension rods, 1¼ ins. in diameter, were placed beside each strut and brought into tension with turnbuckles.

"This system of strutting was constructed at two points in the trestle, and practically takes up all vibration, but under the influence of a heavy freight train I have see these strut timbers buckle from ¼ to ⅜ in. out of line in the direction of their least dimension.

"The necessity for this strutting has become so apparent that I provide for it on other important trestles of extreme length by using a modification of the original plan."

Had Mr. Kelley tried the experiment of bringing the train to rest suddenly on the trestle with the air brakes, he might have found a vibration even greater than the 1½ ins. observed, although this is large enough. Mr. Kelley's remark about the buckling of his longitudinal timber struts from the longitudinal thrusts of heavy trains ought to be sufficient to convince even the most skeptical that such thrusts do exist and that they are carried down to the ground by the columns.

Mr. Parsons' transit observations on one of the New York elevated railroads gives additional evidence of the effects of thrust from braked trains. Mr. Waddell.

How any one can deny that large vibrations are injurious to metal-work, it is difficult to conceive; for, as before stated, they put a double bending moment on the columns, and tend to work loose the rivets that connect the deck thereto.

Mr. Nichols and two or three other engineers question the author's assumption of 20% as the coefficient of friction for the thrust of a braked train. Trautwine places it as high as 25%, while Messrs. Cooper, Schneider and other writers of standard specifications make it 20 per cent. As for the distribution of the thrust, the rails and guards on tangents certainly tend to distribute it over some distance, especially when the track is new; but, on sharp curves and with old track, it would not be proper to place much reliance upon such distribution. Moreover, why divide up the thrust, when assuming it concentrated produces such beneficial results to the whole structure by increasing its rigidity? When the columns are fixed at both top and bottom, as is the case on all of the author's Chicago work, the lever arm of the thrust is only one-half of the unsupported length of the column, consequently the bending moment and the section of column derived therefrom are by no means excessive. This is shown by the comparatively small weights of metal of the author's designs, as given on page 349, viz., 391 lbs. per lineal foot per track for a four-track structure on private property, 385 lbs. per foot per track for a double-track structure on same, 485 lbs. per foot per track for a double-track structure spanning a double-track cable railway in streets, and 571 lbs. per foot per track for a double-track structure in streets spanning from curb to curb with 41 ft. between centers of columns. It is true that these figures are for the comparatively light live load assumed for the Northwestern Elevated, but the assumption of a heavier live load would affect little else than the sections of flanges of longitudinal girders, and in street lines those of cross-girders also.

From the tables in Mr. Nichols' paper* entitled "The Brooklyn Elevated Railway," the author has compiled the following weights of metal per lineal foot of double-track structure, omitting the weights of station metal and not considering the "Old Brooklyn Line." For columns on curbs the weights run from 1 095 lbs. for a 32-ft spacing up to 1 469 lbs. for a 45½-ft. spacing, and for columns in the street 1 195 lbs. The corresponding weights for the Chicago Union Loop are 1 375 lbs. for a spacing of 41 ft., and 1 150 lbs. for columns in the street. If an interpolation for a 41-ft. spacing is made in Mr. Nichols' weights, 1 344 lbs. will be found; and, averaging this with the weight of structure for columns in street, 1 270 lbs. is obtained, as against 1 263 lbs.,

* *Proceedings*, Institution of Civil Engineers, Vol. cxxvii, p. 333.

Mr. Waddell. the corresponding average for the Union Loop, showing that the author's Chicago structure is a little lighter than the average for corresponding lines in Brooklyn, in spite of the fact that the author's live load is on an average for all parts of the structure 17½% greater than that used in designing the Brooklyn lines, as indicated in Mr. Nichol's paper. With such a showing as this, the author cannot be justly accused of extravagance in his designs because he proportioned his columns for the effects of thrust from braked trains and endeavored throughout his entire designs to conform in every particular with the principles of design enumerated in his paper.

If anyone doubts the advantages of putting a little extra metal into the columns and fixing them at both top and bottom, let him stand for a while on one of the platforms of the Union Elevated Loop of Chicago and note the vibration, then try the same experiment on a number of the elevated railroads of New York and Brooklyn, and compare the results. He would probably be considerably surprised; for he would find hardly a tremor on the Chicago road, while on some of the Eastern roads the vibration would be so great as to prevent him from writing legibly in a note-book.

Wooden Floor.—Replying to the comments of Mr. Nichols and others on the wooden floor system adopted, the author would state that it was based upon the results of the experience of those who have been operating elevated railroads for many years. Whether both inner and outer guards are requisite is certainly problematical. In railroad bridges the author relies on the inner guards to keep derailed wheels from receding far from the rails, and on the outer guards to space the ties and keep them from bunching.

Mr. Weston has made two or three improvements on the original design for the floor system, notably the use of tie-plates.

Replying to Mr. Stuart's remark concerning the use of short hook bolts, they were necessitated by the 5-ft. spacing of the longitudinal girders.

Mr. Pegram's design for a floor without cross-ties, as adopted for the Kansas City Elevated Railroad, has one very serious fault, viz., that the trough will collect snow and sleet, which in a cold climate would be liable to freeze to such an extent as to stop traffic altogether.

The author cannot agree with Mr. Tomlinson's view that an 18-in. spacing for 6 x 8-in. ties is an improvement on a 14-in. spacing, for the reason that a derailed wheel has a pretty deep hole to drop into when the open space between ties is 10 ins. wide, and that the bumping which would result from climbing over the ties and dropping between them would be liable to cause disaster. Fig. 40 shows relative conditions that would exist with a 30-in. derailed wheel, assuming that the flanges cut into the ties ½ in. at the corners.

Mr. Waddell.

Answering Mr. Belknap's charge expressed thus, "it is difficult to conceive that a railroad company would countenance the gross extravagance of using the most costly grade of timber when the preservative treatment of cheaper grades would give an article much more economical," the author would reply that, in asking for bids on timber, two specifications were used, the first being the author's calling for clear heart timber, and the second that of the Manhattan Elevated Railroad Company allowing a certain amount of sap wood on the corners. The difference in the lowest bid on the two specifications amounted to about 50 cents per thousand, so the president of the railroad company himself decided to adopt the heart timber. In spite of what Mr. Tomlinson says to the contrary, the author thinks that this was a wise decision, for it is the sap wood, both treated and untreated, that fails first.

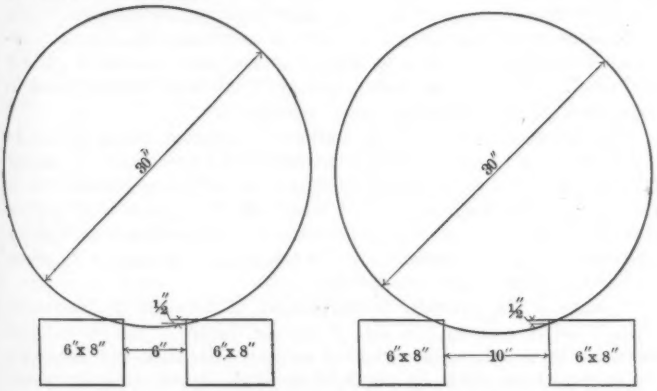


FIG. 40.

Data Concerning Existing Elevated Railroads.—It is possible that the author has, much to his regret, given offence to certain engineers by his sweeping assertion that "the results of his investigation, as far as the designing of the metalwork is concerned, amount simply to the accumulation of a great mass of information exemplifying 'how not to do it.'" Such was certainly not his intention, although the statement was made with due intent and to accomplish an important object. Moreover, later and more extended examinations of existing structures confirm him in his opinion.

The *raison d'être* for his statement is that, when both the Wabash Avenue Extension of the Lake Street Elevated and the Northwestern Elevated contracts were about to be let, the strongest kind of pressure was brought to bear upon the president of these companies to induce him to set aside the author's plans and specifications and to adopt

Mr. Waddell. others submitted by bidders on the plea that the latter were the same as those used for the New York and Brooklyn elevated railroads, which roads represented practically the *ne plus ultra* of both design and manufacture. It was with great difficulty that the author overcame this opposition; but, thanks to the sound business policy of the president, he was finally successful in having both his plans and his specifications adopted and adhered to. Were it not for this stand which he then took, the unscientifically designed and crudely manufactured structures of the New York and Brooklyn elevated railroads would still be the criterion of excellence for that class of construction, notwithstanding the fact that the Metropolitan Elevated of Chicago, then in course of construction, is in most particulars greatly their superior.

The true reason why elevated railroads have been so unscientifically designed in the past is that, as a rule, the designing has been left almost exclusively to the manufacturing companies, which, being more interested in profits than in anything else, naturally detailed the metalwork so as to have it go through the shops quickly and erect readily; and all considerations of scientific design appear to have been ignored because of these requirements.

The intent, therefore, of the author's "sweeping assertion" is to establish for all future elevated-railroad work a precedent for taking the designing and the preparation of the specifications entirely out of the hands of the manufacturer of structural metalwork and placing them where they belong, viz., in the hands of the consulting engineer and expert in such construction. Whether the attempt will prove successful or not, remains to be seen.

Thanks to the courtesy of Mr. Clarke, in forwarding an advance copy of his discussion, the author was convinced of the necessity of having a thorough examination of all the New York and Brooklyn elevated railroads made by a competent engineer, in order to enable him to answer properly, not only Mr. Clarke's discussion, but also those of like tenor, the writers of which take exception to the author's "sweeping assertion." It was therefore decided that the author's chief office assistant, Ira G. Hedrick, Assoc. M. Am. Soc. C. E., should proceed east to make the necessary examination and report. Following are extracts from his letter of instructions:

"You will please proceed to New York at your earliest convenience and examine thoroughly all the elevated railroads of both New York and Brooklyn, with a view to ascertaining whether they show any signs of incipient failure, and, if so, what such failures consist of and the causes thereof. After your examination is finished, you will please make me a full and elaborate report of the results of your investigations. In this report I desire you to point out all departures in detailing from the requirements of good construction as outlined in my paper on elevated railroads, and indicate the evil effects of such departures, if there be any. You will, when in New York, call on the Secretary of the American Society of Civil Engineers and obtain from

him copies of all the discussions of my paper, so as to include in your investigations a study of all points concerning existing elevated railroads that are raised in said discussions. In reporting to me you will please answer all such points, so that I can incorporate your report in my *résumé*, and thus let you reply for me to the statements made in the discussions." Mr. Waddell.

In accordance with these instructions Mr. Hedrick spent a couple of weeks in New York and Brooklyn making his investigations, and after his return presented a report from which the following extracts are made:

"Referring to the discussion of O. F. Nichols, M. Am. Soc. C. E., the writer is of the opinion that in most instances in the New York and Brooklyn lines the connections of columns to foundations are strong enough to take care of all stresses that ever come upon them. Plenty of anchor bolts are used, and these are carried well down into the foundations, and the cast-iron bases grip the feet of columns firmly, so long as the cement or filling used between the column and casting is well preserved. Where columns are placed in the roadway, cast-iron bases, such as are used for the Second Avenue line in New York, or for the Kings County Elevated in Brooklyn, are probably as satisfactory and economical as any that can be used. But where columns are on curbs, or on private property, the column foot shown on Fig. 5, which was used on the Northwestern Elevated Railway, is equally as good and certainly much more economical."

"Where the bases are made of structural steel, no lugs are used on the columns, but the anchor bolts merely pass through the base plate and angles connecting the column to the base plate. Four anchor bolts are used for each column, and they are placed very near the corners of the base plates; therefore the strength and rigidity of the connection between the column and the pedestal depend entirely on the ability of the corners of the base plate and angle to resist bending. This style of base is certainly not so strong as where the anchor bolts pass through bent plate lugs which are firmly riveted to the feet of columns, as is done in the detail used for column bases on the Northwestern and Union Loop Elevated Railways in Chicago.

"In regard to the actual amount of longitudinal thrust load from braked trains, and the distribution of this load over the structure, there seems to be considerable difference in opinion among engineers, and Mr. Nichols takes a very decided stand against the assumptions used in designing the Northwestern and Union Loop Elevated Railways.

"While it is no doubt true that the assumption that 20% of the greatest live load between two expansion joints acts as a horizontal thrust upon the columns between same is on the side of safety, yet it is a fact that light columns and weak connections between columns and cross-girders are probably the causes of more vibration in the existing elevated structures in New York and Brooklyn than are all the other objectionable features combined. On all of these structures, excepting in one or two instances, a very perceptible longitudinal vibration can be felt when the brakes are applied to a train, and in the taller portions of the Second and Eighth Avenue lines these vibrations seem to have an amplitude of from one-half inch to an inch.

"On most of these lines there is an expansion joint in each panel, which arrangement makes each bent act alone in resisting the longi-

Mr. Waddell.

tudinal thrust that may come upon the panel attached thereto, excepting, of course, the aid it may receive through the track system.

"The writer cannot agree with Mr. Nichols in regard to the continuity of track and the consequent distribution of this horizontal thrust or traction load, as all joints in the track rails and guard timbers must adjust themselves for expansion and contraction of the metal superstructure, and consequently the whole structure is practically non-continuous over expansion joints; therefore the most scientific and rational way to design the columns and cross-girders is to proportion them so that each section of structure between expansion joints can take care of itself entirely independent of any other part of the structure.

"On the portion of the Suburban Rapid Transit Line which rests on brick piers there is, as stated by Mr. Nichols, absolutely no vibration, although the longitudinal girder construction is similar to that of other portions of the structure which are supported on steel columns and in which there is considerable vibration, yet not so much as in many of the older lines. This structure on brick piers certainly demonstrates the truth of your column theory in a most impressive way, and shows conclusively that the great cause of vibration in ordinary construction lies in the columns and their details, and the writer is therefore convinced by his observations that metal, properly applied, is never wasted in columns, although the sections may seem heavy.

"On none of the elevated railways in New York and Brooklyn is any attempt made to carry the longitudinal thrust directly into the columns by lateral struts, and consequently there is considerable cross bending on the transverse girders where the columns are placed on the curbs and where the tracks are located near the center of the streets. But this bending does not affect the structure so much where the cross-girders are double and where the columns are in the street and the tracks placed over them. The bad effects of this bending are noticeable on some of the down-town lines, in which there is a slight canting of the cross-girders when the brakes are applied to passing trains, and in some cases the bolts attaching the longitudinal girders to cross-girders have to be frequently replaced.

"By extending the lateral bracing out to columns and thus firmly fixing their tops, as is done on the Union Loop Elevated Railway in Chicago, the bending on cross-girders is entirely avoided and a much more rigid construction is secured, which can best be appreciated by standing on the last-named structure while the brakes are applied to trains. The writer regrets that he could not take vibration curves on the various structures he inspected so as to give a more definite idea of their relative rigidities, and prove conclusively the superiority of the well-braced structure.

"The writer agrees with Mr. Nichols in regard to the spacing of expansion pockets, and the greater rigidity of the structures in which they are spaced from 150 to 250 ft. apart is very noticeable. The limiting distance for spacing expansion pockets depends upon the stresses produced in columns by the expansion and contraction of longitudinal girders due to changes in temperature. The more rigid the columns, the greater will be the temperature stress for any given distance between expansion pockets, and *vice versa*. For the Union Loop the limiting distance was found to be 150 ft., but on the Suburban Rapid Transit Line, with expansion pockets 250 ft. apart, the metal in columns is probably not strained any higher by temperature stresses than that in Union Loop columns, on account of the much less rigid column section used on the Suburban Rapid Transit Line.

Mr. Waddell.

"In regard to column sections, there is certainly a great diversity of opinion among engineers, as is evident by the many different styles used on the lines in New York and Brooklyn, and it is certainly a difficult task to design a column which is satisfactory in every respect. The Phœnix column and a column made of two channels laced together are used on the New York and Brooklyn elevated roads more than are any of the other styles. There are objections to both of these columns. The Phœnix column is inaccessible for paint on the inside, and consequently its interior is subjected to the unmolested ravages of rust. It may be claimed that no moisture can get inside the column, and therefore that there is no necessity for the application of paint; but that an abundance of moisture and water finds its way to the inside of these columns is proved by the fact that during the winter season these columns are often burst open by the freezing of the accumulated moisture inside. The possible occurrence of such a result makes another serious objection to the Phœnix column.

"The two-channel column with double-riveted lacing is certainly the most satisfactory column used on any of the elevated railways in New York or Brooklyn, but in most instances its efficiency is largely destroyed by cutting the column off below the bottom of the cross-girder. The Fifth Avenue Line in Brooklyn and the Third Avenue Line in New York furnish examples of this defective style of construction, and will be considered later on in this report. The columns built of two channels laced together usually have the webs of channels placed parallel to the center line of structure, so that the webs of channels carry the shear from longitudinal thrust, and the lacing carries the shear from transverse loads. The double-riveted lacing is surely ample to carry the transverse loads due to wind, but on curves the centrifugal load could be much more satisfactorily carried by solid webs, as there is in all cases considerable vibration from trains passing around curves. Two 15-in. channels with webs turned parallel to center line of structure do not give nearly as strong a section longitudinally as two channels and one I-beam, the section used on the Union Loop of Chicago. This I-beam column is just as satisfactory, as far as proper connections are concerned, as the two channel column, and is certainly much more rigid in both transverse and longitudinal planes.

"The investigations made by the writer verify your assertion that all columns should be extended up to tops of cross-girders, which should be solidly riveted into them.

"The assertion by Mr. Nichols that the later structures in New York have the tops of columns so firmly fixed that the structures could be slid bodily over the ice without the columns collapsing would, in the writer's opinion, apply only to the Suburban Rapid Transit Line in New York.

"The straight brackets in use on most of the lines in New York and Brooklyn consist of two small angles with two and three rivet connections to cross-girders and columns, and are almost absolutely useless as bracing. The rivets in these connections work loose, showing that the details are weak and overstrained. A straight bracket with a solid web would be more efficient than a curved bracket, but less pleasing in appearance, but the curved bracket with a solid web is incomparably better than the angle brackets in such common use on the older lines.

"Referring to the discussion by T. C. Clarke, M. Am. Soc. C. E., the writer made a careful examination of the Second Avenue Line

Mr. Waddell. in New York, and in the following pages each of the seventeen essentials of good construction given in your paper are applied to the above-named structure and the evil effects of the violation of these essentials are pointed out.

"*1. Insufficiency of Rivets for Connecting Diagonals to Chords of Open-Webbed Girders.*—The diagonals in the longitudinal girders of the Second Avenue Line are each composed of two angles varying in size from 6 x 4 ins. at ends to 4 x 3 ins. at center. The diagonals are of the single-intersection Warren girder type, and in no case do they intersect on center-of-gravity lines. There are only four or five rivets connecting these diagonals to the chords, and as there are no connection plates in the girders, the rivets connecting the diagonals to the chords are bunched in such a small space that it is hardly probable that the full value of these few rivets is obtained. Some of these rivets are working loose, but not so many as would be expected. Judging from the investigations made, there is probably, on the Second Avenue Line, an average of about twenty loose rivets per mile per month in the diagonals of longitudinal girders. This number is only about one-third as many as are found on the Third Avenue Line, but certainly many more than should be found on a structure which has been properly designed.

"*2. Failure to Intersect Diagonals and Chords of Open-Webbed Girders on Gravity Lines.*—In none of the longitudinal or transverse girders of the Second Avenue Line do the diagonals intersect on gravity lines, while near the ends of these girders where large angles are used these diagonals intersect in some cases as much as 8 ins. off centers.

"It will be interesting to take the case of a 45-ft. span (Fig. 41) and figure the combined direct and bending stress on the top chord. The loads assumed for these calculations are the same as were used in designing the Union Loop.

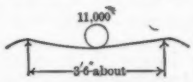
Dead load per lineal foot of track .. 700 lbs.
Live load " " " .. 2 500 "

Total load " " " .. 3 200 lbs., or, 1 600 lbs per lineal foot per stringer.

"Moment at center of girder $= \frac{1}{8} \times 1\,600 \times (45)^2 = 405\,000$ foot-pounds. Effective depth of girder $= 3.25$ ft. Stress $= \frac{405\,000}{3.25} =$ 124 600 lbs.

"Bending on top chord. Let us use the compromise formula $M = 0.1\ Wl$.

Live load, $M = 0.1 \times 11\,000 \times 42 = 46\,200$ inch-pounds.



Dead load $M = \frac{1}{12} \times 350 \times 35 \times 42 =$ 4 290 inch-pounds.
Total bending moment $= 50\,490$ "

Section for top chord, assumed, two 6 x 6-in. 72-lb. angles.
Moment of inertia of top chord $= 45$ net.

$$R = \frac{4.25 \times 50\,490}{45} = 4\,768 \text{ lbs.}$$

$$\text{Direct stress} = \frac{124\,600}{14.4} = 8\,653 \text{ lbs.}$$

"Total extreme fiber stress in center panel of top chord due to combined direct load and bending = 13 421 lbs. per square inch. This is too high an intensity to use where the loads are so frequently applied as they are on this line. The intensity used for the top chord sections on the Union Loop was 9 000 lbs. Mr. Waddell.

"Let us try the end detail of these longitudinal girders. End shear = 22.5 x 1 600 = 36 000 lbs.; eccentricity = 12 ins.; moment due to eccentricity = 36 000 x 12 = 432 000 inch-pounds; moment of inertia of section on *A B* (Fig. 42) = 160 net; $R = \frac{3.5 \times 432\,000}{160} =$ 9 450 lbs., which is all right.

"Let us try an intermediate panel point "X," Figs. 41 and 43. Direct stress in second panel of top chord = $\frac{36\,000 \times 7}{3.25} = 77\,540$ lbs. Therefore $P = \frac{77\,540}{14.4} = 5\,385$ lbs.

$P = 5\,385$ lbs. Stress in diagonal = 15 600 lbs.

Bending from wheels $R = 4\,768$ " Lever arm for eccentricity = 8 ins.

Moment = 8 x 15 600 = 124 800 inch-pounds.

Bending due to eccentricity $R = 11\,787$ " $R = \frac{4.25 \times 124\,800}{45} = 11\,787$ lbs.

Total extreme fiber stress = 21 940 "

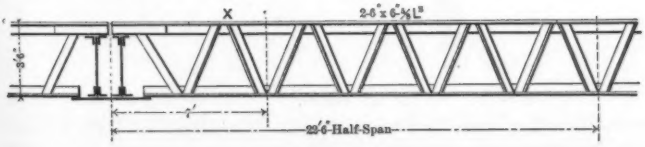


FIG. 41.

"This is too high to strain the top flanges of these girders. From the above figures it will be seen that the eccentric connections are the cause of more stress in the top chords than the combined direct load and bending due to wheel loads. Such unnecessary stresses should certainly not exist in a well-designed structure.

"*4. Failure to Proportion Top Chords of Open-Webbed Longitudinal Girders to Resist Bending from Wheel Loads in Addition to Their Direct Compressive Stresses.*—From the figures made for Section 2, it will be seen that the stresses in top chord angles are not excessive for the combined direct load and bending due to wheel loads on top chords, but that the stress due to eccentric connections combined with the two cases named above increases the total intensity to about 100% above what it should be. With proper connections the top chords of this structure would not be overstrained more than 45 per cent.

"*5. Insufficient Bracing on Curves.*—On the Second Avenue Line no bracing is provided on curves, except the ordinary stringer bracing. As a result of this neglect, the stringer bracing connections on curves

Mr. Waddell. are badly overstrained, and the rivets are continually working loose. The bracing frames between adjacent stringers seem to suffer especially from the centrifugal load, and as the diagonals in these frames are of small flat bars, connected by one rivet at each end, and at the intersection at center, they are entirely inadequate for the work they have to do. There is great vibration on all curves caused by passing trains, although their speed is much reduced as they approach the curves.

"On Twenty-third Street, where the line runs from First Avenue to Second Avenue, there is a short tangent between two very sharp curves, and the lack of sufficient bracing is clearly shown by the swaying of the structure in both transverse and longitudinal directions as the trains pass around these curves.

"Rigid bracing frames placed at center of panels would add greatly to the rigidity of the structure. A comparison of the action of this structure with that of the Union Loop Elevated in Chicago under similar loads and conditions would show the great advantage to be derived from a rigid lateral system on curves.

"*6. Insufficient Bracing between Adjacent Longitudinal Girders.*—On the entire Second Avenue line the adjacent longitudinal girders are

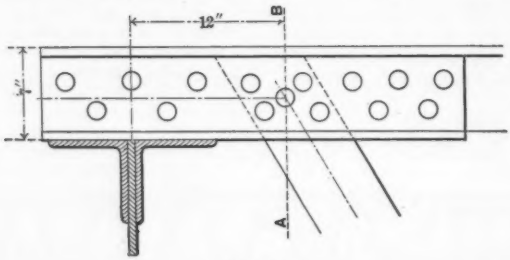


FIG. 42.

braced together with 3 x 3-in. angles in the planes of both top and bottom flanges, with a bracing frame at each end of panel, and one or more at intermediate points according to length of span. As stated before, the diagonals in the bracing frames are of small flats and of very little value as bracing. The bracing angles between the adjacent longitudinal girders are ample to carry all stresses which can come upon them where the structure is on tangent, but as no plates are used for connecting these angles to the longitudinal girders, only two rivets are used to attach them to the girders. These two-rivet connections do not stand the wear and tear of the constant vibration produced by the heavy traffic, and as a result many of these rivets work loose. The single rivets in the bracing frame connections also frequently work loose. Enough metal has been used in the bracing between longitudinal girders to make a thoroughly rigid system if properly distributed. If the bracing angles between bottom flanges of girders had been omitted and the same amount of metal were used in providing suitable connection plates and rigid bracing frames joining the longitudinal girders at the center of panel, and if all connections were made with three or more rivets, the structure would be more rigid and there would be no trouble with loose rivets in the lateral bracing.

Mr. Waddell.

"*8. Excess of Expansion Joints.*—In the Second Avenue structure, provision is made for expansion in every panel, and this excess of expansion joints is one great cause for vibration in the structure. Neglecting the continuity of the track, each bent has to take care of all longitudinal thrust from traction or braked trains coming on the panel which is attached to it. There can be no real necessity for the expansion joints on this line being placed closer than at every fourth bent, or, say, from 175 to 200 ft. apart, and such an arrangement would add a great deal to the rigidity of the structure.

"*9. Resting Longitudinal Girders on Top of Cross-Girders Without Riveting Them Effectively Thereto.*—The attachment of longitudinal girders to the gross-girders on the Second Avenue line is the same for both fixed and sliding ends, except that the holes for the bolts used in the connections at sliding ends are slotted and are provided with washers, while for the fixed ends the holes are made to fit the bolts or rivets. The connection of longitudinal girders to the cross-girders is not well designed to transmit the longitudinal thrust from the former to the latter. The bolts connecting the ends of the lower flanges of the longitudinal girders to the cross-girders are missing in a great many instances, especially in portions of the structure on curves.

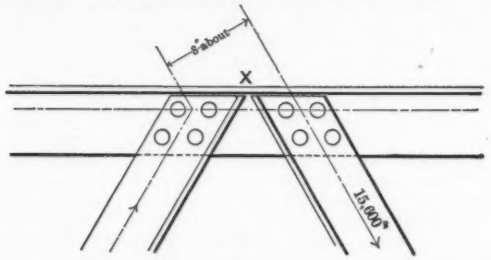


FIG. 43.

"The end details of these longitudinal girders have a great deal to commend them from a manufacturer's point of view, as they are simple, and no special details whatever are required for the sliding ends.

"*10. Cross-Girders Subjected to Horizontal Bending by Thrust of Trains.*—No struts are used on the Second Avenue line in any case to carry the thrust from braked trains to column direct, but the cross-girders are relied upon to carry this load in bending. Throughout the entire line all cross-girders are composed of two separate girders, each of four angles and a solid web plate, or a lattice web system. These girders have stay plates between them at all points where the longitudinal girders connect to the cross-girders, so these heavy cross-girders are probably amply strong to carry all transverse bending that comes upon them in portions of the structure where the columns are located in the street beneath the tracks. But on portions of the structure where the columns are placed on curbs, the bending should be taken care of by means of struts extending out to the columns. On some of the down-town portions of structure with the columns located on curbs, there is a perceptible canting of the cross-girders when the brakes are applied to passing trains, and the writer was told by persons in a position to know that this torsion on the cross-girders is the cause of a great many rivets and bolts working loose.

Mr. Waddell. "*11. Cutting Off Columns Below the Bottom of Cross-Girders and Resting the Latter Thereon.*—The columns on this line are all cut off below the bottoms of cross-girders and are provided with cast-iron caps which are bolted to the tops of columns and to the cross-girders. The cross-girders are double, as previously described, therefore they furnish quite a large bearing area on top of columns. A large plate 1 in. thick is inserted between the cast-iron cap and the bottom of cross-girders, and about twelve $\frac{7}{8}$-in. bolts are used in the connection of cross-girders to columns. This detail, of course, does not fix the tops of columns in such a rigid way as the details used on the Union Loop of Chicago, but the connection is as strong in every way as it is possible to make it when the columns are cut off below cross-girders. The writer could find none of the bolts in these connections loose, and he was informed by others that only a very few of these bolts had ever been replaced.

"No diaphragms are used between the cross-girders directly over the columns, and it occurred to the writer that if a solid diaphragm had been put in between the two cross-girders, directly over the center of the column, riveted to both girders and bolted to the top of column, it would practically have made a fixed end of the top of column, so far as the cross-girders are concerned. Such details for tops of columns cannot be commended, because the only rigidity which can be obtained in such connections is due to the ability of the bolts to resist direct tension, and certainly better results can be obtained at much less cost by running up the columns and riveting the cross-girders into them.

"*12. Paltry Brackets Connecting Cross-Girders to Columns.*—The brackets used on the Second Avenue line are small cast-iron sections curved to circular form, and bolted at one end to the cross-girders and at the other to the column. If these brackets were put on merely to improve the appearance of the structure, they may, to a certain extent, be said to fill the purpose for which they were intended, but if they were intended to serve as braces to aid the column in any way, they are certainly useless.

"*13. Proportioning Columns for Direct Live and Dead Load and Ignoring the Effects of Bending Caused by Thrust of Trains and Lateral Vibration.*—The columns used on this Second Avenue line are of Phœnix sections and contain ample metal to resist all stresses that ever come upon them if they were firmly fixed at the tops in both transverse and longitudinal directions. The vibration in this structure is not due to lack of metal in columns, but to numerous defective details as outlined previously. While there is considerably more vibration in this structure than there should be, it is, nevertheless, the most rigid and durable of any of the elevated roads in New York, excepting the Suburban Rapid Transit line and the City Hall approach, and the better condition of this Second Avenue line is due largely to the great amount of metal used in its construction. As nearly as the writer can estimate the weight of this structure, it contains about 30% more metal per lineal foot of structure than does the Union Loop of Chicago. A large portion of this metal is in the columns and cross-girders.

"As before stated, the Phœnix columns on this line are often burst by the freezing of accumulated water on the inside of the columns. This water must get into the column by the bolt holes at top, through which the bolts pass that attach the cross-girders to the column, also through the holes in the sides of columns through which the bolts pass that connect the curved cast-iron brackets.

Mr. Waddell.

"*14. Omission of Diaphragm Webs in Columns Subjected to Bending.*—The Phœnix column requires no diaphragm and is well adapted to carry shear in any direction.

"*15. Ineffective Anchorage; 16, Column Feet Surrounded by and Filled with Dirt and Moisture; 17, Inefficient Bases for Pedestals.*—The bases of the columns are made of cast iron, and into these cast-iron bases the column is set in cement or rust grouting. The joints between the columns and castings are in good condition, and there are no evidences of any springing or movement of the columns. The cast-iron bases are extended far enough above the ground to prevent the dirt and moisture from accumulating around the steel column. The columns are not badly rusted, considering the length of time this structure has been built. Each of these cast-iron bases is anchored to the masonry by four anchor bolts which extend to the bottom of pedestal. The anchorages are so strong that the columns and pedestals would act as one piece if tested to destruction. There have been but few if any repairs made to the anchorages and pedestals, nor has there been any settlement of the foundations. It is the opinion of the writer that the pedestals, bases and anchorages are first class, and if all parts of the structure were as well designed as these portions there would be but little adverse criticism to make.

"From the foregoing you will note that the writer does not agree with Mr. Clarke's statement that the Second Avenue line conforms in general design to all of the seventeen essentials named in your paper, and maintains that Nos. 1, 2, 5, 8, 9, 10 and 11 of the defects named do exist in a very distinct form in the Second Avenue line, and that the evil results of such defects are plainly shown by the action of the structure under loads and by the necessity for repairs which are being made from time to time.

"Mr. Clarke's figures of $319 per mile per year seem a large amount to pay out for repairs to metalwork alone, exclusive of painting and trackwork. The writer is of the opinion that on a structure designed like those shown in your paper, the cost of repairs to metalwork alone would be practically nothing for the first 20 or 30 years; and with no increase in the live loads, the life of such a structure, kept well painted, would be indefinitely long.

"The writer wishes it to be understood that he does not criticise the design of the Second Avenue line as not being fully up to the standard of good construction at the time it was built, and he appreciates the fact that the art of steel construction was in its infancy 20 years ago, and that it has been by a process of evolution that the designs of to-day are so far superior to those of the earlier days.

"*General Criticism of All the Elevated Railways in New York and Brooklyn.*—In accordance with your request, the writer extended his investigations to all the elevated railways in New York and Brooklyn, and in the following report will take up the 17 defective points mentioned in your paper, and apply them to all of these lines, and will show that some of these exist in all of the structures mentioned, and all of them in some of the structures.

"*1. Insufficiency of Rivets for Connecting Diagonals to Chords of Open-Webbed Girders.*—The longitudinal girders on the Third Avenue line were originally made with single intersection webs, each diagonal being composed of two angles; but with increased live loads and constant traffic these girders began to wear out so rapidly that it became necessary to strengthen them. This strengthening was done by putting in another set of diagonals, each diagonal being composed of two

Mr. Waddell

flat bars which pass between the original angle diagonals at their centers and are riveted to them at their intersection by one rivet. No connecting plates are used in any of the connections of diagonals to chords, and even with the additional set of diagonals the girders are weak.

"If the loads were equally distributed between the two sets of diagonals, the number of rivets in the connections of diagonals to chords would be ample; but, as the added diagonals are capable of taking tension only. they are of but little value, and the end connections are still overstrained, as is shown by the number of loose rivets to be found in them.

"The construction of the longitudinal girders in the Ninth Avenue line is very similar to that of the Third Avenue line.

"The longitudinal girders in the Kings County Elevated are of much better design ; for in most cases plenty of rivets are used, as the diagonals are connected to web plates in top and bottom chords.

"2. *Failure to Intersect Diagonals and Chords of Open-Webbed Girders on Gravity Lines.*—On none of the lines where lattice girders are used has there been any attempt to intersect the diagonals on gravity lines, and this is no doubt one of the great causes for the wear on these girders."

"4. *Failure to Proportion Top Chords of Open-Webbed Longitudinal Girders to Resist Bending from Wheel Loads in Addition to Their Direct Compressive Stresses.*—No webs are used in the top chords of longitudinal girders in any of the New York lines, but as the panels are very short in most instances, the bending on top chords from wheel loads does not produce excessive strains in them.

"On the Kings County Elevated, heavy web plates about 15 ins. wide are used between both top and bottom chord angles, which are ample to resist the bending from wheel loads in addition to the direct stresses. The connections are eccentric, and the stresses due to the bending from eccentric connections are greater than those from the bending due to loads on top chords.

"To make a comparison of the details of the longitudinal girders used on the Union Loop in Chicago, and some of the New York and Brooklyn elevated roads, the writer herewith gives some typical details of the different designs in Figs. 44, 45, 46 and 47.

"By a careful inspection of Fig. 44, which shows the details of the longitudinal girders used on the Union Loop, it will be seen that all diagonals intersect on the center-of-gravity lines of the chords, thus eliminating all secondary stresses, while the diagonals of girders shown in Figs. 45, 46 and 47, do not intersect on gravity lines ; consequently large secondary stresses are produced in all said designs.

"It will also be noticed that in the Union Loop design ample provision has been made for bending on top chords, by providing a web plate between the two top chord angles, that large connecting plates are used for connecting diagonals to bottom chords, and that more rivets are used in all connections of diagonals than in the girders of the other structures.

"The girders for the Kings County Elevated, Fig. 45, have heavy web plates in top and bottom chords, and, although more metal is used in these girders than in those for the Union Loop, none of the diagonals intersect on gravity lines. The end detail of these girders which furnishes the bearing on cross-girders is very eccentric, and it will be seen that on the section on *AB*, Fig. 45, there is a large bending moment which must be taken up by the top chord and the reinforcing

Mr. Waddell.

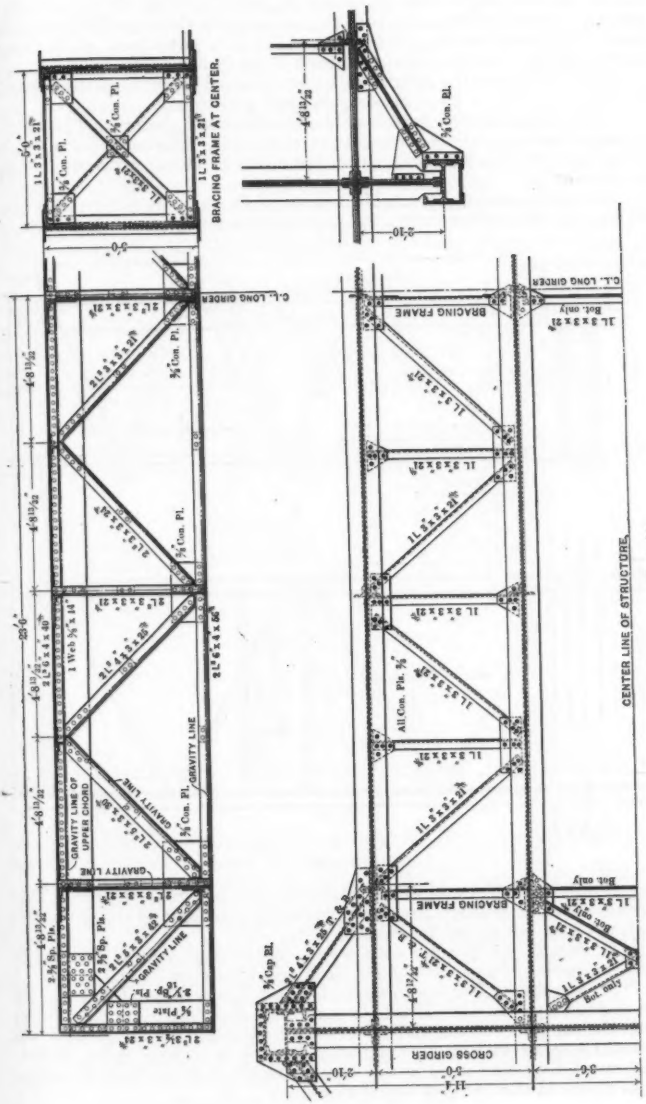


FIG. 44.

Mr. Waddell. angles at the end; but the reinforcing angles are cut off so near the point of maximum bending that there is a great shear on the few rivets back of the section line AB which could easily have been avoided by extending the reinforcing angles back 12 or 15 ins. farther.

"Fig. 46 shows the details of the longitudinal girders on the Second Avenue line, which have been considered previously.

"Fig. 47 shows the details of the longitudinal girders on the Third Avenue line since they have been re-enforced. The eccentric connections, light top chord section, and few rivets in all connections should be noted.

"There is one commendable feature of the girders shown in Figs. 45 and 46, which that shown in Fig. 44 does not possess, and that is

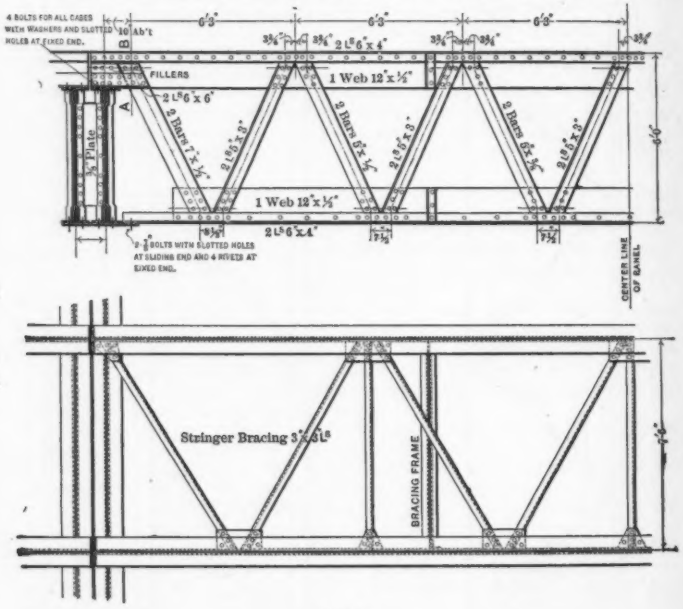


FIG. 45.

the projection of the top flange angles above the cross-girders. This arrangement of girders gives an unbroken surface of longitudinal girders on which to lay the ties.

"*5. Insufficient Bracing on Curves.*—No special lateral bracing is used on curves of any of the New York and Brooklyn lines.

"*6. Insufficient Bracing between Adjacent Longitudinal Girders.*—On the Second Avenue, the Third Avenue, and the Ninth Avenue lines, both the top and bottom flanges of adjacent longitudinal girders are braced together with angles connected to girders by two rivets, no connection plates being used in any case. On all of these lines there are loose rivets in the bracing connections.

Mr. Waddell.

"*7. Pin-Connected Pony Truss Spans and Plate Girders with Unstiffened Top Flanges.*—Pony truss spans are used on the greater portion of the Sixth Avenue line, and of all the structures which the writer has examined, this one is undoubtedly in the worst condition. The evidences of wear and tear are too numerous to mention. The vibration is excessive, and loose rivets are plentiful.

"*8. Excess of Expansion Joints.*—With two or three exceptions, all of the lines in New York and Brooklyn have expansion joints at every panel. Two of the exceptions are the Fifth Avenue line in Brooklyn, in which the sliding ends are placed at every third bent, or about 150 ft. apart, and the Suburban Rapid Transit line, in which they are placed at every fifth bent, or about 225 ft. apart. The longitudinal rigidity gained by spacing the sliding ends as in the last-named structure is

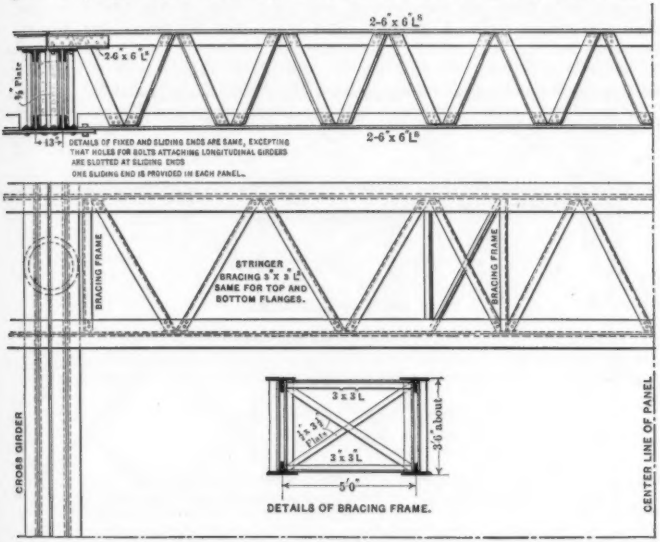

2-6" x 6" L°
2-6" x 6" L°
2-6" x 6" L°
DETAILS OF FIXED AND SLIDING ENDS ARE SAME, EXCEPTING THAT HOLES FOR BOLTS ATTACHING LONGITUDINAL GIRDERS ARE SLOTTED AT SLIDING ENDS
ONE SLIDING END IS PROVIDED IN EACH PANEL.
BRACING FRAME
STRINGER BRACING 3" x 3" L° SAME FOR TOP AND BOTTOM FLANGES.
BRACING FRAME
CROSS GIRDER
3 x 3 L
3 x 3 L
3'6" about
5'0"
DETAILS OF BRACING FRAME.
CENTER LINE OF PANEL

FIG. 46.

very noticeable by comparing them with the structures in which the expansion joints are placed in every panel.

"*9. Resting Longitudinal Girders on Top of Cross-Girders Without Riveting Them Effectively Thereto.*—Various details are used on the different lines for attaching the longitudinal girders to cross-girders. The details adopted on the Kings County, the Second Avenue, and the Third Avenue lines are shown in Figs. 45, 46 and 47, and these are typical of those used on all of the older lines. On the Suburban Rapid Transit line in New York, and the Fifth Avenue line in Brooklyn, the longitudinal girders are riveted into the cross-girders, the top flanges of the former passing beneath those of the latter.

"The connections of longitudinal girders to cross-girders on the older lines are not designed to resist properly the thrust from braked trains, as will be seen from Figs. 45, 46 and 47.

Mr. Waddell. "A great many of the rivets and bolts attaching the longitudinal girders to the cross-girders work loose, especially those at bottoms of longitudinal girders.

"*10. Cross-Girders Subjected to Horizontal Bending by Thrust of Trains.*—On none of the lines in New York or Brooklyn is any special bracing used to carry the thrust from braked trains directly to the columns, and thus relieve the cross-girders from the transverse bending which comes upon them. A slight semblance of such bracing is used on the Kings County Elevated, but the struts are of small single angles, which are placed in planes of bottoms of longitudinal girders only, and are not capable of carrying the stresses which come upon them.

"On most of the older structures the cross-girders are all double, consequently they are capable of carrying more horizontal bending than are single-webbed girders, and when the columns are placed

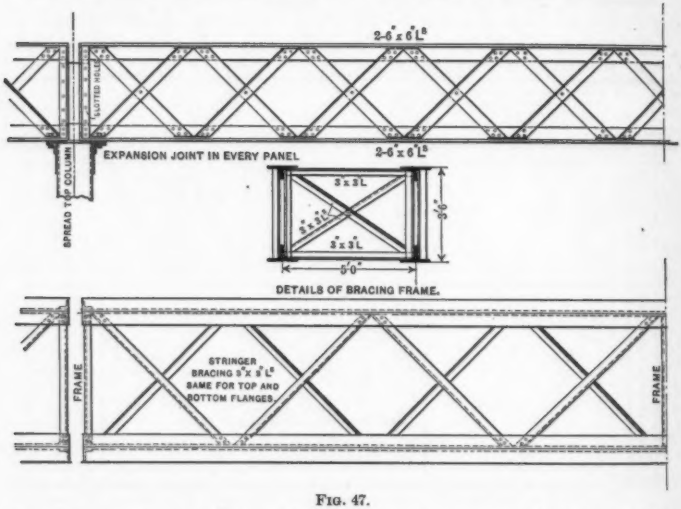


FIG. 47.

beneath or quite near the tracks, they are strong enough to carry the thrust to the columns; but where columns are set on curbs, the bending effect of braked trains is noticeable in the vibrations of the structure, and in some cases by the canting of the cross-girders.

"The bracing used on the Union Elevated Railway of Chicago to take up the thrust from braked trains, also to fix the tops of columns, is shown in Fig. 44. From some of the discussions, the writer believes it will be interesting to give in this connection the method used in determining the size of these struts and the strength of their details.

"Let us assume the span length to be 50 ft.; live load = 1 800 lbs. per lineal foot of track (equivalent load for 150 ft. span); total live load on one panel per track = 50 x 1 800 = 90 000 lbs.; coefficient of friction = 0.20; longitudinal thrust = 90 000 x 0.20 = 18 000 lbs.; distance from center to center of columns = 22.66 ft.; thrust on one

column $= \frac{18\,000 \times 17.33}{22.66} = 13\,770$ lbs.; the depth of longitudinal girder is 5 ft., unsupported length of column = 16 ft. (see Fig. 48). Mr. Waddell.

"As this bracing is designed to fix the tops of columns, and as the bottoms of columns are firmly fixed by the anchorages, the lever arm is equal to one-half the unsupported length of column, or 8 ft.

$$\text{Stress on lower strut} = \frac{13 \times 13\,770}{5} \text{ sec. } \theta = 42\,246 \text{ lbs.}$$

$$\text{Stress on top strut} = \frac{8 \times 13\,770}{5} \text{ sec. } \theta = 25\,998 \text{ lbs.}$$

"The unsupported length of these struts is about 4 ft. Least radius of gyration, two 4 x 3-in. 25-lb. angles = 1.2. Therefore, $\frac{l}{r} = \frac{48}{1.2} = 40$. Hence, these struts are good for 12 000 lbs. per square inch. They are, therefore, strong enough to fix the tops of columns. From Fig. 44 it will be seen that eight rivets are used for the bottom struts; then stress on each rivet in the connection for bottom strut $= \frac{42\,246}{8} = 5\,281$ lbs., and for those in the connection for top strut $= \frac{25\,998}{6} = 4\,333$ lbs. These stresses are well within ordinary working intensities. From these calculations, it will be seen that the tops of columns are fixed by these struts, and that all members and details are strong enough to take care of the stresses produced by the assumed thrust of 0.20 of the live load.

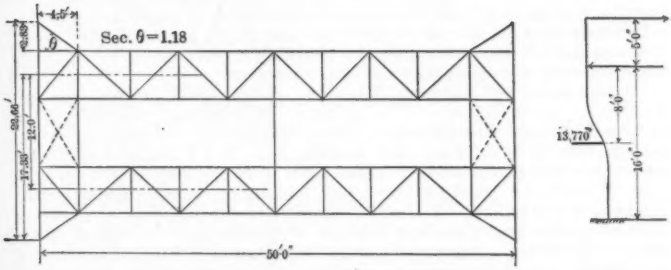


FIG. 48.

"Having thus shown the method used in determining the size of struts required to fix the tops of columns, the effect of this horizontal thrust will now be used in proportioning a column.

"Assuming the same span length as before, we have the following:

"Live load =	2 440 lbs.	per lineal foot of track (equivalent live load for 50-ft. span).	
"Dead load =	650 lbs.	per lineal foot of track.	
"Total	= 3 090 lbs.	" " "	
"Total load on one column from longitudinal girders		3 090 x 50 =	154 500 lbs.
"Weight of one column and half of one cross-girder.			6 500 "
"Total direct load on one column			161 000 "

Mr. Waddell. "The total longitudinal thrust on one column, as given above, is 13 770 lbs. One-half unsupported length of column = 8 ft. or 96 ins. Bending on column = 96 x 13 770 = 1 321 920 inch-pounds. Section used for column { 2 15-in. 100-lb. channels. 1 15-in. 123-lb. I-beam. } Area of section = 32.3 sq. ins.

"The web of I-beam is placed parallel to center line of structure.

"The moment of inertia of section = 1 300 net.

"Therefore the stress on extreme fiber

$$= \frac{8 \times 1\,321\,920}{1\,300} = 8\,135 \text{ lbs.}$$

"Stress from direct load = 5 000 "

"Total stress on extreme fiber due to combined direct load and bending moment = 13 135 "

which is allowable under such an unusual loading, as $\frac{l}{r}$ is less than forty-five.

"From the foregoing calculations it will be seen that all parts of the structure are designed to resist properly the assumed horizontal thrust; and it is interesting to note also that, although all possible combinations of stresses under the most unfavorable conditions are properly taken care of, the structure does not weigh as much per lineal foot as some of the older designs in which no provision is made for such stresses, although they are liable to occur.

"*11. Cutting off Columns Below the Bottom of Cross-Girders and Resting the Latter Thereon.*—The columns of nearly all the structures in New York and Brooklyn are cut off below the bottoms of cross-girders, except in the City Hall approach in New York, and on a portion of the line on Broadway in Brooklyn. On the City Hall approach the columns are built of two 15-in. channels, laced together with double-riveted lacing. The inner channel is cut off below the bottom of cross-girder, and the outer channel is extended to the top of cross-girder, the latter being riveted into this channel. This construction is certainly much better than that used on most of the New York lines; but the connection would be more rigid if both channels were extended to top of cross-girder, and if a diaphragm were placed between the two channels and extended down to the bottom of the curved bracket beneath the cross-girder.

"The detail used for attaching the cross-girders to columns on the Rapid Transit line, New York, and given by Mr. Berger in Fig. 35, is certainly a good one, as it makes the cross-girder and column practically continuous, and is at the same time comparatively easy to manufacture and erect.

"On all lines where Phœnix columns are used, the columns are cut off beneath the cross-girders, and are provided with cast-iron caps to which the cross-girders are attached by means of bolts. This style of construction, with its defects, was discussed in connection with the Second Avenue line.

"On the Third Avenue line the columns are composed of two 15-in. channels connected with double-riveted lacing, and are flared out at the top to receive the longitudinal girders which rest thereon. The connections between columns and girders are very weak, and are not capable of resisting properly the longitudinal thrust.

"The curving of channels at tops is objectionable, for, according

to the reports of shop inspectors, the channels often crack while being bent. Another objectionable feature of this style of column is that where the concentrations from longitudinal girders come upon the edge of the column, there is very little metal to carry the load. There are many failures in the details at tops of the columns on the Third and Ninth Avenue lines, and in many instances bent plates have been used to reinforce them. Mr. Waddell.

"The bolts and rivets which attach the longitudinal girders to the tops of columns fail in a great many instances, and in some cases the tops of columns have been reinforced with bent plates. A portion of the Ninth Avenue line is constructed in the same manner. On the Fifth Avenue line in Brooklyn the columns are built of two 15-in. channels with double riveted lacing bars. The inner channel is cut off below the bottom of cross-girder, and the outer one is extended up about 18 ins., and riveted to end of cross-girder. The detail is similar to that used on the City Hall approach, but not nearly so good.

"*12. Paltry Brackets Connecting Cross-Girders to Columns.*—The brackets used on the Second Avenue line have been described, and the same style of brackets is used on all structures having Phœnix columns.

"The columns on Third Avenue are flared out at top and thus form a kind of bracket. The brackets on the Sixth Avenue line are made of a single 3-in. or 4-in. T-iron and connected to columns and cross-girders by four small rivets about $\frac{5}{8}$ in. in diameter, at each end. These brackets are absolutely useless so far as providing any lateral rigidity to the structure is concerned.

"On the Kings County Elevated the brackets are made of two 3 x 3-in. angles connected to cross-girders and columns by three rivets or bolts. These brackets are very weak, and add but little, if any, rigidity to the structure.

"A portion of the Fifth Avenue line in Brooklyn has brackets composed of two 6 x 6-in. angles attached to cross-girders and columns by four rivets at each end of strut. These brackets are strong enough to take care of any stress that comes upon them. On some portions of this line, where the structure is only of ordinary height, the brackets are omitted, and as the connection between cross-girders and columns is weak, as previously described, the tops of columns are almost free ended. This portion of the structure is very vibratory, in fact the writer believes the vibration at the Sixteenth Street station on this line is greater than at any other elevated station in New York or Brooklyn.

"The City Hall approach has curved brackets with solid webs which serve their purpose well.

"The brackets on the Suburban Rapid Transit line are made of two 4 x 3-in. angles, bent at ends onto cross-girders and columns, and connect by six rivets. These brackets, and the superior details used to connect the cross-girder to column help to make the structure rigid transversely.

"*13. Proportioning Columns for Direct Live and Dead Loads and Ignoring the Effects of Bending Caused by Thrust of Trains and Lateral Vibration.*—If all details were made so as to fix properly the tops of columns in both transverse and longitudinal planes, the sections used for the columns on most of the lines in New York and Brooklyn would be strong enough to carry satisfactorily all the loads that could ever come upon them.

Mr. Waddell. "*14. Omission of Diaphragm Webs in Columns Subjected to Bending.*—A great many of the columns used on the various lines are of Phœnix section, and consequently do not require diaphragms, and on several lines where channel columns are used the lacing is double riveted. The writer could see no signs of failure in any of the lacing on columns, even where single riveted lacing is used.

"*15. Ineffective Anchorages.*—The writer believes that the anchorages on nearly all the lines he examined are strong enough to carry satisfactorily all the combinations of stresses which ever come upon them.

"*16. Column Feet Surrounded by and Filled with Dirt and Moisture.*—There are a number of designs used for column feet on the different lines in New York and Brooklyn, but in nearly all cases the bases are made of cast iron, and are extended well above the surface of the ground, serving as fenders where the columns are placed in the street. The feet of the Phœnix columns are, in general, as well preserved as could be expected considering the age of these structures, and the little attention these bases have received. If the feet of columns were kept properly painted, and if the joints between the columns and the cast-iron bases were kept well filled with grouting, these bases would be entirely satisfactory.

"The bases of columns on the Third and Sixth Avenue lines and on a portion of the Ninth Avenue line are very different from those used with the Phœnix columns. As well as the writer could determine, these columns, which are in the street, are set in a cast-iron base which is entirely below the surface of the pavement, and a separate cast-iron fender is used above. These bases are not so satisfactory as those previously described, and in many cases the fenders are broken and the feet of columns are badly rusted.

"The column bases on the Suburban Rapid Transit line are made of cast iron and the bottoms of columns are filled with grouting. The feet of these columns are in good condition.

"On a portion of the line on Broadway in Brooklyn, the bases are made of cast-iron and are solidly riveted to the feet of columns. These castings rest on stone pedestals which project 18 ins. or 2 ft. above the pavement and serve also as fenders. These column feet are in excellent condition; the connections of columns to bases are very strong, and their bases are in turn attached to pedestals by four anchor bolts. There is no place for moisture or dirt to accumulate, and for durability and efficiency these bases are probably superior to those used on any of the other elevated lines in New York or Brooklyn.

"*17. Insufficient Bases for Pedestals.*—The writer could not secure much information concerning the pedestals, but so far as he could learn there has never been any trouble from the settlement of foundations, and therefore it is probable that ample bases have been provided for the pedestals.

"*18. Neglect of Painting the Metalwork.*—It is surprising to note the false economy practiced on all the elevated railways in New York and Brooklyn, by failing to keep the metalwork properly painted. It is safe to say that there is not a single line which is not badly in need of repainting.

"Without doubt the almost unmolested erosion of the metal on the older structures has done more to destroy them than the wear and tear due to both the heavy traffic and the excessive vibration from defective details. It is only a matter of time, and not a very long time either, unless some very effective means are employed to arrest the

ravages of rust, until the older structures will have to be rebuilt. It is indeed remarkable that metalwork, the value of which runs up into millions of dollars, should be left to rust away, when a comparatively small sum of money, spent at the proper time and for the right kind of painting, would prolong the life of the structure indefinitely. The writer believes that the subject of painting should have received more consideration in your paper, as it is certainly a most important one. Engineers should certainly use their influence to prevent such great losses to the companies, which losses are as sure to come from lack of painting as from faulty details." Mr. Waddell.

From what Mr. Hedrick says it will be seen that Mr. Clarke was a trifle hasty when he stated that the Second Avenue line of New York "conforms in general design to all of his (the author's) sixteen 'essentials,' although in details there are many differences." In truth, there are very few of said essentials of good construction that were not violated in the design of this Second Avenue line; although there is this to be said in its favor—a plentiful, or, strictly speaking, an extravagant, use of metal reduces considerably the magnitude of the ill effects of the violation of first principles of design; and, considering the lack of knowledge about structural metalwork at the time it was designed, it is a creditable piece of engineering work. Nevertheless, this is no reason why it should continue to be a model for future elevated railroads.

Treated Versus Untreated Timber.—It appears that Mr. Stuart and Mr. Belknap question the correctness of the data used in comparing the real values of vulcanized and untreated timber, so it behooves the author to make good his premises.

Most of his information concerning vulcanized yellow pine was obtained in conversation with the late Colonel Hain, who was for many years general manager of the Manhattan Railway Company. Unfortunately there is no documentary evidence to verify the conversation mentioned, but the author is able to give the following extract from a letter by Colonel Hain to Professor F. Holbein, of Berlin, Germany, which will substantiate the statement that the former approved of vulcanized timber for elevated railroads:

"We first began the use of vulcanized wood in the spring of 1883. One million feet of vulcanized cross-ties and planking was placed on the line of our road that year, expressly to give it a fair trial on its merits. After the lapse of six years, a careful and critical examination was made of the vulcanized material laid in 1883. We found it entirely free from decay, and as sound and sweet as the day it was laid. There were no indications of decay at the end of the vulcanized planking, while the planks and cross-ties not treated, placed on the structure at the same time, were decayed at the ends and where they were nailed or bolted to the supporting timbers.

"Since the foregoing examination, we have been using vulcanized material exclusively on the line of the road. Actual experience has satisfied us that vulcanizing is far superior to any other known treatment for prolonging the life of timber. We find that vulcanized ma-

Mr. Waddell.

terial neither wears out nor decays. We have had no occasion to take up any of it since we commenced its use.

"Our experience with creosoted ties proved unsatisfactory. Creosoting seems to soften timber and weaken its spike-holding quality. We have found great trouble in keeping spikes in place, especially on curves. Spikes in vulcanized wood we find are as firmly fixed after the lapse of ten years as when first driven.

"Vulcanized wood does not seem affected by wind, rain, heat or sun. Before we adopted vulcanized wood it was necessary to constantly employ 150 men painting our structure. Since its adoption, we have only 60 painters, who work on the iron part of the structure exclusively. Vulcanized wood needs no paint to protect it.

"The average life of untreated ties and timber on our structure has been about five to six years."

Here is a distinct disagreement between Mr. Stuart and Colonel Hain concerning the life of untreated timber on elevated railroads. Mr. Stuart challenges the author's assumption that the life of such timber is as short as seven and a half years, while Colonel Hain says that on his lines it has been about five or six years. The author's experience with timber trestles in various parts of the United States indicates a life of from five to eight years for untreated yellow pine; although in certain cases a couple of years longer duration has been obtained by renewing defective parts and bolstering up the structure in different ways.

In order to satisfy Mr. Belknap's doubts concerning the efficiency of the vulcanizing process and the comparative values of vulcanized and untreated timber, the author has collected quite a mass of written evidence, extracts from which are given in the appendix.

Bearing Capacity of Chicago Soil.—The author regrets that, as pointed out by Mr. Weston, his statement that Mr. Rowe found the safe load per square foot for Chicago soil as low as 1 000 lbs., should cause any misconception concerning the character of the foundations for the Northwestern and Union Loop Elevated Railroads. Mr. Rowe's discussion, though, will clear up any such misunderstanding.

Best Style of Anchorage for Columns.—Answering Mr. Nichols' statement that the author duplicated in his column anchorage for the Sioux City train-shed the corresponding detail used for the St. Louis Union Depot, the author would reply that the design for the former was made in June, 1891, before anyone did any figuring at all on the St. Louis train-shed.

Best Sections for Columns.—Answering Mr. Nichols' statements that no one has ever made a very satisfactory column from I-beams, and that the Z-bar column is "unsatisfactory when it comes to connections with girders or with column feet," the author must take issue with him; for it would be difficult to evolve a more satisfactory column for street work than that formed of two channels with an I-beam between, as used throughout the Union Loop. The author does not mean satisfactory to the manufacturer or to the erector, but satisfactory to the party who pays for and operates the structure. These

columns are not only extremely rigid, but also are well calculated to resist deformation from the heavy blows to which they are occasionally subjected by the street traffic. As for the Z-bar column of the Northwestern Elevated, one could not ask for better connections for detailing; and certainly the column thus far has proved satisfactory in every respect, although it has not yet been subjected to the test of traffic. Mr. Waddell.

Replying to Mr. Nichols' question as to why the columns for Designs 12 and 13 have larger sections than those for Design 3, the author would state that the latter design involves the use of longitudinally braced towers, while the other designs do not. In Design 3 there is only direct vertical load on the columns, while in the other designs there are both vertical load and cross bending.

Mr. Connor criticises the Z-bar column on account of its expense in manufacture; but when one considers that when the Northwestern metalwork contract was let the pound price bid was very much lower than any price previously tendered on elevated work, notwithstanding not only the alleged difficulty in manufacturing the columns, but also the reaming clause, the importance of his criticism reduces practically to zero. It must be remembered that the ultimate object in designing metalwork is to obtain results and not to keep down to the lowest possible limit the cost of manufacture.

The columns of two channels with flared ends advocated by Mr. Connor are defective for two reason: first, the bending is injurious to the metal, and, second, the bearings for the longitudinal girders are inadequate. Mr. Hedrick refers to these points in his report upon the New York and Brooklyn elevated railroads.

Best Style of Expansion Joint.—The author never claimed that he evolved his design for expansion pockets out of his inner consciousness. It represents simply an improvement on the older designs, in that the load from the longitudinal girder is applied as closely as practicable to the web of the cross-girder, and in that the weight of metal required is reduced to about a minimum, with due regard for both direct load and bending caused by eccentricity.

Distance Between Expansion Joints.—In respect to the best distance between expansion joints, the author would call attention to the fact that when the columns are fixed at top and bottom, the effect of variation of temperature is greater than where one end is loose, and that the extremes of temperature in Chicago are somewhat greater than those at New York. On these accounts he still prefers to adhere to 150 ft. as the regular limit, with an occasional length of 200 ft. at most, where the conditions necessitate it. The author's calculations were based upon an assumed extreme of expansion and contraction equal to 1 in. in 100 ft., although he considered it probable that not much more than three-quarters of this would be found after erection.

Mr. Waddell.

Superelevation on Curves.—Mr. Nichols must remember that it is intended to operate the Northwestern Elevated at much higher speed than ever before adopted for an elevated railroad, hence the author's "apology for a compromise between theory and practice in using low elevations of the outer rail on curves."

Answering Mr. Nichols' surmise that none of the connections of the author's columns to girders are either very simple or thoroughly effective, the author begs to submit through Mr. Hedrick's report some detail sketches of the tops of the columns for the Loop. From these sketches it will be seen that the column tops are connected rigidly by an ample number of rivets to substantial struts that form part of a complete system of lateral bracing, and that the connecting rivets are in direct shear. It is shown by these sketches that "close adherence to the scholastic methods has not led to the retention of some of the antique errors of girder construction."

It is evident from Mr. Nichols' figures that the spans on his Brooklyn Elevated could have been made a trifle shorter, so far as economy is concerned; however, if he will deduct the cost of all the lateral bracing, and will compare that of the longitudinal girders alone with that of the bent, he will not find as much difference as 30 per cent. It is very easy to see that if the cost of a bent be practically constant for small changes in length of longitudinal girders, and if the cost per foot of the latter vary directly with the span, the greatest economy will exist when the cost of a bent is equal to the cost of the longitudinal girders of one span.

In order to reply to Mr. Nichols' claim that an earth embankment with concrete retaining walls would be cheaper than the structure adopted for the Northwestern Elevated, the author has made such a design with an estimate of cost, and finds that, on the contrary, the embankment would cost fully 7% more. The data for the estimate are as follows:

Height of embankment above street, 16 ft.; width of embankment out to out, 48 ft.; thickness of both wall and buttresses at top, 18 ins.; thickness of wall at top of footing course, 3 ft.; that of buttresses at same elevation, 6 ft.; width of footing course for wall, 5 ft., and that for buttresses, 8 ft.; depth of foundation, 5 ft.; front face of wall vertical; rear face stepped off by 6-in. offsets; three horizontal 1½-in. rods used to tie together each pair of opposite buttresses transversely to line; vulcanized ties 8 ins. x 8 ins. x 9 ft. spaced 2 ft. centers; price of concrete $7 per cubic yard; cost of metal 2.5 cents per pound; cost of earth in place 30 cents per cubic yard; cost of excavation, including back-filling, 50 cents per cubic yard; cost of rails for both cases, $2 per lineal foot of track; cost of vulcanized timber in place $36 per M., B. M.

The length of line considered is one city block of 292 ft., of which

the street takes 72 ft. and the alley 20 ft., leaving exactly 100 ft. as the length of each retaining wall. As it is not practicable to tie together opposite buttresses in the end walls, the entire end walls were made of the same section as the buttresses of the side walls. Mr. Waddell.

The following is the detailed estimate of cost:

Two Embankments.

Concrete	1 502 cu. yds.,	at $7 00	$10 514 00
Earth	4 187 "	" 30	1 256 10
Excavation	782 "	" 50	391 00
Ties	400	" 1 75	700 00
Rails, etc.	800 ft. of track	" 2 00	1 600 00
Metal	16 400 lbs.	" 2.5 cents	410 00
Grouting around the rods			200 00
Total			$15 071 10

Metal Structure over Alley.

Metal	20 000 lbs.	at 2.5 cents	$500 00
Floor	20 ft. "	$23 00	460 00
Total			$960 00

Metal Structure over Street.

Metal	132 000 lbs.	at 2.5 cents	$3 300 00
Floor	72 feet "	$23 00	1 656 00
Pedestals	6 "	100 00 (av.)	600 00
Total			$5 566 00

Summation.

Embankment	$15 071 10
Over alley	960 00
Over street	5 556 00
Total	$21 587 10

or, $73 93 per lineal foot.

Cost of Metal Elevated.

Metal, per foot, 1 765 lbs. at 2.5 cents	$44 13
Floor and rails, per foot	14 32
Pedestals (32 at $96) ÷ 292	10 52
Total cost per lineal foot	$68 97

Mr. Waddell. The schedule prices used in these estimates are the same as those adopted for the preliminary estimates of cost for the Northwestern Elevated. Moreover, they have since proved to be almost exactly right, except that the concrete in foundations was somewhat cheaper; but as the concrete for the walls will be more expensive than that in the pedestals on account of the more complicated and larger forms required and the smooth finish of the exterior, it has been considered best to let the price stand unchanged.

The difference in cost per foot in favor of the metal structure is $4 96, or a little over 7 per cent.

The adoption of the embankment design would increase the cost of right-of-way almost as much as it would that of the construction, for, although it would not affect the price of the land occupied by the structure, it would affect the amounts to be paid as damages to adjacent property. These will average as high as 30% of the cost of the land occupied by the structure. The reason for the smaller damages for a steel structure is that with it the railroad company is able to grant to adjacent property owners access to the damaged property from the right of way, which could not be done were the embankment design adopted. The author has been informed by one of the officials of the Northwestern Elevated, who is best posted on right-of-way matters, that the additional amount to be paid for damages on account of the embankment design would be not less than 15 per cent.

The advantages of the embankment design are, first, a reduction in cost of painting to one-third of that for the metal structure, and, second, lowering the grade about 3 ft. To offset these there are the extra first cost of construction and right of way, the more rapid deterioration of the ties in the embankment, and the prevention of use of ground beneath the structure for storage purposes, small shops, etc. This last item is an important one, especially as the ground will become more and more valuable for such purposes as the city continues to grow and develop in the neighborhood of the line.

Answering Mr. Nichols' criticism of the design for anchor bolts, take the worst case on the Loop, where the spans are, say, 50 ft. long, making the distance between expansion points 150 ft., and load two of the three spans to the maximum, making the live load on one track about 200 000 lbs., for which the thrust would be 40 000 lbs., or 13 333 lbs. per bent. The spacing of tracks being 12 ft. and that of the columns 22 ft. 8 ins., the portion of the 13 333 lbs. going to the nearer column would be about 10 000 lbs. The greatest unsupported length of column, measuring from the under side of the thrust strut to the bottom of the base plate, is 25 ft.; and, as the column is fixed at both ends, the point of contraflexure will be at the middle, making the lever arm for the thrust 150 ins. and the overturning moment 1 500 000 inch-pounds.

Mr. Waddell.

In order to make all the conditions as bad as possible for the detail, no live load will be placed on the bent considered, and as the dead load per track, including weight of bents, is 800 lbs. per lineal foot, the dead load on the column is 40 000 lbs. It is difficult to say where is the center of upward pressure to resist this weight; but, if it be assumed at the same distance from the axial plane as are the anchor bolts, or 9½ ins., no great error will be made. This makes the righting moment 380 000 inch-pounds, leaving for the net overturning moment 1 120 000 inch-pounds; dividing this by the 19 ins. between opposite anchor bolts gives about 59 000 lbs. as the stress on the two anchor bolts. As these are 1⅛ ins. in diameter, the intensity on the metal will be about 17 000 lbs., which, though high, is not excessive.

As this is the worst possible case, and as all the anchor bolts for the line pedestals are of the same diameter, there is evidently sufficient strength in all of said bolts; and, moreover, there is no great waste of metal in the anchor bolts for the shorter columns. Again, on various accounts one would not think of using bolts of much less diameter on account of possible future rust, especially as the diameter is reduced at the root of the thread.

The next matter is whether the anchor bolts project far enough into the concrete, as Mr. Seaman, Mr. Berger and others appear to question the propriety of not carrying them down to the bottom. In the first place it must be noticed that the mass of concrete is truly monolithic; and, as the function of the bolts is to make the column and the concrete act as one piece in resisting overturning, it will suffice if the tensional strength of the concrete at the end of the bolts be as great as that of the acting bolts.

Now it must be noticed that only one pair of anchor bolts can act at a time, and that the ultimate strength of this pair is about 55 000 lbs. per square inch, or 194 000 lbs. The area of the concrete at the ends of the bolts is 49 sq. ft., or, say, 7 000 sq. ins. If the tension be distributed uniformly over one-half of this area, the intensity will amount to less than 60 lbs., which is far below the ultimate tensile strength of even the poorest concrete.

Now, as to whether the rods are long enough to distribute their pull into the concrete, above the anchor casting, past experiments prove that they are amply so; but, even if they are not, the anchor plates will provide a proper distribution without overstraining the concrete.

It is, therefore, evident that there is no necessity whatsoever for carrying the rods any lower than they were carried.

In connection with the pedestals there remains but one point to be taken up, viz., whether the pedestals themselves have weight enough to resist the assumed overturning for which the anchor bolts were proportioned.

Mr. Waddell.

In the worst case on the Loop, the point of flexure in the column of which is about 20 ft. above the bottom of the concrete, the base of the latter is 10 ft. square. Taking the center of moments at one edge of the base, the overturning moment is 200 000 foot-pounds. The total vertical load on the base is composed of the 40 000 lbs. of dead load on the column, the weight of concrete, which is about 66 000 lbs., and the weight of earth on top of the pedestal, which amounts to about 36 000 lbs., making a total load of 142 000 lbs.

If the resisting moment of the weight is limited to that existing when the intensity of pressure at one edge of the base reduces to zero, the lever arm of the resisting moment will be one-sixth of the width of base, or 1.666 ft., and the greatest resisting moment therefore will be 142 000 x 1.666 or about 236 000 foot-pounds.

It is therefore evident that, even if the earth about the pedestals were not tamped in, the pedestals are large enough to resist properly the overturning effect of the assumed thrust used in proportioning the anchor bolts.

As for the pedestals on the Northwestern Elevated, the conditions are quite different, the anchor bolts, of which there are but two per pedestal, being required primarily for the assumed transverse load of 600 lbs. per foot of span. If the length of the latter is taken as before at 50 ft., the total thrust is 30 000 lbs, or 7 500 lbs. per pedestal. The greatest unsupported length of column is about 16 ft., and, as both ends are fixed, the lever arm is 8 ft., making the overturning moment 60 000 foot-pounds. By assuming no train on the track of the column considered, the only load on the column will be the dead load, which amounts to about 32 000 lbs., and as its lever-arm is $7\frac{1}{2}$ ins., the resisting moment will amount to 20 000 foot-pounds, making the net overturning moment 40 000 foot-pounds, or 480 000 inch-pounds, for which the lever arm is 15 ins., and therefore the stress on the single rod 32 000 lbs., or a little over 18 000 lbs. per square inch.

The point of flexure in the column is 17 ft. above the base of the pedestal, thus making the overturning moment 127 500 foot-pounds.

The total load on the base of the 8-ft. square pedestal consists of 32 000 lbs. on the column, the weight of the concrete, amounting to about 48 000 lbs., and that of the earth above the pedestal, amounting to about 20 000 lbs., making a total load of 100 000 lbs., for which, as in the previous case, the lever arm is one-sixth of the length of the base, or 1.333 ft., making the greatest righting moment 133 000 foot-pounds, which is a little more than the overturning moment, showing, as before, that, even if the earth in the pits be not tamped, the pedestals are of ample size to resist properly the greatest overturning moment of the assumed loading.

It is therefore proved that all the adverse criticism of the design of the pedestals on both the Loop and the Northwestern Elevated is with-

out foundation, and that the consequent objections to these designs are purely imaginary. Mr. Waddell.

Mr. Seaman says, referring to the New York and Brooklyn structures:

"These elevated roads, after twenty years of service, under loads exceeding those for which they were designed, show no indication of such deterioration as would justify the prediction of the author that they will eventually be reconstructed because of their faulty details."

Perhaps Mr. Seaman will change his opinion about this after reading Mr. Hedrick's report. If on some of these structures 100 rivets per mile of double-track elevated road must be replaced each month by reason of their failure or working loose, as was stated to Mr. Hedrick, does it not show that the details are greatly overstrained and that the structure is in consequence gradually wearing out? The author's experience with ordinary railroad bridges of antiquated construction has been that, when such structures begin to fail in details, they sooner or later have to be taken out and replaced, in spite of all the patchwork that may be done on them.

Mr. Seaman asks for the details of the author's estimates, meaning probably the schedule prices adopted. The principal ones are as follows:

Metal erected and painted, $2\frac{1}{2}$ cents per pound; vulcanized timber in place, $38 per M., B. M.; rails with their details and fastenings in place, three 80-lb. rails per track, $1 80 per lineal foot per track; concrete, $7 per cubic yard; and excavation, including back-filling, 50 cents per cubic yard.

What metal is saved in Design 7 is required for end stiffeners and cover plates for cross-girders as compared with Design 6, thus making the weight of metal per lineal foot the same for both designs.

Design 8 is lighter than either of these designs on account of the greater simplicity of the horizontal bracing resulting from the abutting of the outer longitudinal girders against the columns, notwithstanding the "cross-girder strains and brackets," referred to by Mr. Seaman.

It would not be feasible in such a paper as this to give every detail of all the estimates made.

Answering Mr. Bouscaren's questions, the greatest variation in temperature was assumed to produce a variation in length of metalwork equal to 1 in. per 100 ft.; the wind load (or more strictly speaking the transverse horizontal load) assumed was 450 lbs. per lineal foot for the double-track structure, and 600 lbs. per lineal foot for the four-track structure; the speeds of trains assumed varied from 40 to 20 miles per hour according to the degree of the curvature; and all curves are compounded. The intensities of working stresses adopted in making the designs were as follows:

Flanges of longitudinal plate girders, extreme fiber, 8 000 lbs., allowing one-eighth of the web to act as a part of each flange; tension

Mr. Waddell. flanges of open-webbed, riveted longitudinal girders, 9 000 lbs.; compression flanges of same for combined bending and direct load, 9 000 lbs.; diagonals of same, from 6 000 to 8 000 lbs., according to the relative dimensions of angle legs; flanges of transverse girders, 9 000 lbs., allowing one-eighth of the web to act as a part of each flange; columns in compression only, $12\,000 - 45\frac{l}{r}$; columns for combined direct loads and bending of all kinds, including temperature effect, 20 000 lbs., where $l \div r$ does not exceed 45.

Mr. Horton points out that the author's elevation of base of rail is 21 ft., above the street. This applies only to the Loop, where various considerations necessitate a higher track level than that of the Northwestern, for which the height is from 18 to 19 ft. The height of the car floor was a fixed quantity, as it had to be made the same as on the other lines using the Loop.

Answering Mr. Mogensen's remarks concerning a solid floor, the author would state that the latter would not dispense with the use of timber ties, unless it involved great noise in operation; hence, Mr. Mogensen's first claim will not hold.

As an example of noisy operation in a structure where there is no timber cushion under the rails, the Park Avenue viaduct of the New York Central Railroad may be mentioned. On this structure the noise from a passing train sounds like that of an approaching tornado.

If Mr. Mogensen were to make a complete design for a structure with a solid floor that would be comparatively noiseless, he would probably find, as the author has found, that the extra cost would amount to much more than 15 per cent.

There was an error made in the preliminary edition of the paper in respect to the composition of granitoid, which has been corrected. Mr. Stuart's criticism, however, would now apply with still greater force, as the composition is less rich in cement than was stated. As it was Mr. Weston who specified and put in this granitoid, the author wrote him, sending a copy of Mr. Stuart's remarks, and has received the following in reply:

"Mr. Stuart's conclusions in respect to porosity of the mixture which we have used for the pedestal blocks on the Northwestern Elevated railroad are erroneous. The fact is that the texture of the finished stone is very compact and free from voids. The mixture, when properly manipulated, produces a stone which resists perfectly the action of frost.

"We have on the Northwestern Elevated road several thousand pedestals made from this mixture. These pedestals have been during the past winter exposed to temperatures of 20 degrees below zero. I have only recently examined personally nearly every pedestal on the line, and I failed to find one among them which gave any evidence of deterioration.

"As to the strength of the stones made from the mixture specified, they are superior in every respect to those made from the best lime-

stones mixed with sand and cement mortar. Furthermore, it is the mixture in common use in Chicago for the best grades of cement sidewalks and continuous curb and gutter construction. Hundreds of such walks and gutters can be seen in perfect condition after having resisted the elements and extraordinary traffic for more than ten years." Mr. Waddell.

The author must take issue with Mr. Trocon concerning the fixedness of column feet, for he is convinced that where four anchor bolts per pedestal are used on his Chicago work, the columns and pedestals are just as continuous as if the former were embedded in the latter to any depth.

The author agrees with Mr. Parsons in his preference for design No. 8. It is the most satisfactory of all the double-track designs figured upon, but, unfortunately, it could not be used on the Chicago work, as all the double-track portion of the structure is located in the street, where a spacing of 17 ft. between centers of columns is inadmissible.

Mr. Connor expresses his regret that facing the end angles of the longitudinal girders was not called for in the author's specifications. The specifications contained this clause:

"The ends of all webs that abut against other webs must be faced true and square or to exact bevel, and the end stiffeners must be placed perfectly flush with these planed ends, so as to afford proper bearing for the ends of the attaching girders."

In order to comply with these requirements the Union Bridge Company decided to make the end stiffeners $\frac{1}{2}$ in. thick and to plane the ends of the girders after the stiffeners were riveted on, while the Elmira Bridge Company chose to plane the webs first and then put on $\frac{3}{8}$-in. stiffeners to fit the planed webs exactly. The latter company, however, agreed to use thicker stiffeners and to rivet them on before planing, in case the inspectors reported the work to be unsatisfactory when done by the method last described. No complaint on this score has as yet been made, or, in truth, on account of any other matter concerning shopwork; and the author feels that he cannot speak too highly of the character of all the shopwork done thus far on his Chicago work by both the Union and Elmira Bridge Companies.

Mr. Hodge seems to think that the stating of correct principles of design for elevated railroads by the author is superfluous; but even to-day in designing structural metalwork these principles are more often honored in the breach than in the observance. As for "guessing" as to the number of extra rivets required for a connection, when the number required theoretically is small, the author maintains that two rivets do not make a proper connection except for lacing, and that when the number of rivets required by pure theory comes out almost exactly three or even four, it is better to add another rivet as a matter of precaution.

Mr. Waddell. The author agrees with Mr. Weston that, all things considered, it would have been better to place the top flanges of the longitudinal girders a little above those of the cross-girders instead of a little below. The result would certainly facilitate laying the track, but would require a little more metal and would involve a somewhat clumsy detail at the junction. On the connection of the Metropolitan Elevated to the Union Loop, which connection was designed by the author, such a detail was adopted at the request of the officers of the Metropolitan Company. In future work the author would not attempt to make the top flanges of consecutive longitudinal girders continuous or semi-continuous over the cross-girders; but would cut them square off so as to clear the top flanges of the latter, upon which he would place pieces of steel buckled plate to receive the ties.

The author is glad to see Mr. Lindenthal's remark about the separation of incoming and outgoing passengers. If he could have his own way on this question, the author would make this a *sine qua non* in designing all stations for elevated railroads. The Northwestern stations, as he designed them, certainly provide for such a separation; and it is to be hoped that they will be built that way, although there is now some talk of abandoning the exit stairways.

Mr. Lindenthal has failed to recognize the fact that there will be no side view of the four-track portion of the Northwestern Elevated possible except at street crossings, and that consequently the difference in depths of longitudinal girders at the braced towers can never be noticed; therefore it would have been a needless piece of extravagance to make the webs of the short girders as deep as those of the long ones.

In respect to the question of æsthetics there seems to be such a variety of opinion that the author concluded to consult several architects of established national reputation and leave to them the settlement thereof. He therefore wrote to Mr. Henry Van Brunt, of the firm of Van Brunt & Howe, Kansas City, Mo.; Mr. Chas. A. Cummings, of Boston, Mass., and Messrs. Carrère & Hastings, of New York City, asking them for criticisms of his designs.

Mr. Van Brunt replied as follows :

"You have asked me for a frank architectural criticism of your proposition to decorate the construction of an elevated railroad, as illustrated in the last pages of your paper presented to the American Society of Civil Engineers February 17th, 1897. The opportunity for the discussion of this difficult problem is so rare that I am disposed to avail myself of it seriously. The relations between our two professions are growing closer, and it is important that we should understand one another better.

"It has been observed that among semi-barbarous nations forms of art are developed from an instinctive conception of beauty, which has free expression because it is not embarrassed or sophisticated in its development by the knowledge of other forms of art indigenous to

other people and resulting from other conditions of material and use. Thus, among civilized nations the accumulation and organization of knowledge, which to every other form of intellectual activity is a stimulus, seems to have proved, at least to some part of the art of the 19th century, a positive impediment. The cultivation of the mind through the knowledge of past achievements has in fact rendered the architect of to-day so self-conscious, and has supplied him with such a multiplicity of conflicting ideals, that his inherent creative power is weakened and his natural initial force is lost in a sort of intellectual timidity and vacillation. With the distractions furnished by his familiarity with history he cannot adjust himself to his own environment with the frankness and *naireté* by which the masters of classic and mediæval times developed architectural style. Mr. Waddell.

"In this respect the modern engineer enjoys a distinct advantage over his brother, the modern architect. Fortunately in the practice of his profession he is not embarrassed by these grave distinctions, and his art has consequently progressed with the general progress of the century. But when, in his bridge truss or his elevated railroad, he has evolved mathematically an economical structure, which commends itself to his own scientific judgment, and to the approval of those whose capital he is investing in a purely commercial undertaking, and finds at last that the results are an offence to the æsthetic instincts of mankind, the correction which he attempts to apply to satisfy this æsthetic instinct subjects him immediately to the very same embarrassments which beset the path of the architect. For almost invariably and inevitably this correction, as in the present case, is a reminiscence or tradition from an entirely different form of structure, and is applied too late in the process of construction to make good art. In fact, the correction is an afterthought; it is applied to a completed fabric, and forces it to assume an aspect which is not a harmonious development of its essential structure, but a concession to an arbitrary and conventional idea of beauty or grace.

"True architecture is construction carried to the highest point of development without the necessary addition of any elements foreign to its own conditions of stability and strength. Structure cannot be elevated into the domain of art merely by the application of ornaments. Ornament is contributory to a work of art and not essential to it. A Cistercian abbey has no ornament, but its rank as a work of art is as high as that of a Clunisian abbey which abounds in the richest decorative accessories. Certainly the true function of ornament is not to conceal or obscure construction, but to illustrate it.

"I very highly appreciate the motive which has prompted your attempt at decorated construction, and I recognize the ingenuity with which you have tried to solve this most difficult of all problems in design, but I beg to call your attention to the fact that this most praiseworthy effort would never have resulted as it has in your careful drawings if your mind had not been pre-occupied by the agreeable effect of the construction of a stone bridge. It is evident, however, that, executed, the phenomena of perspective would destroy this resemblance to this conventional type, and substitute some more or less unexpected and not entirely agreeable effects. It seems to me apparent, moreover, that the important arch form given to the longitudinal web is not an evolution from its essential structure, but is imposed upon it for the satisfaction of an ideal of grace; that the form of the brackets supporting the overhanging footway conceals, and certainly does not illustrate, the member which actually does the work; that the

Mr. Waddell. capitals and base moldings of the supporting piers are imposed upon a structure with which they have no sympathy, and are a reminiscence of forms invented for an entirely different material; and that the decorated entablature is merely a thin screen which does not suggest the structure which it masks, but recalls a structure of a very different sort, and is therefore with its moldings and panels simply a conventional and purely arbitrary symbol intended to agreeably beguile the spectator. You have done what a very large proportion of men in my own profession would have done, if called upon to make your completed construction more attractive to the eye, but all this decoration is applied and not inherent. It does not illustrate the essential and peculiar nature of the fabric and is not a part of it. Therefore, according to ethics of design, however agreeable and interesting to the eye, it is really a costly and ingenious deception and is not true art.

"If the structure without such masks is ungainly and uncompromising, the remedy to be sought for by the engineer should, it seems to me, be limited to bringing together the various members of a perfectly mathematical and economical construction with as much elegance of line and precision and finish of workmanship as he can possibly command. If he can use ornament, let him so use it as to illustrate the construction and not to conceal or weaken it. It is the misfortune of the engineer that he is dealing with a strictly mechanical problem, and is therefore constrained to use materials and methods which have as yet never been developed in the direction of that more perfect union which really constitutes the essential qualities of grace and beauty. I venture the proposition that, following the analogy of nature in the evolution of natural forms, no construction which is coarse or ugly can be perfect construction, and that the reasonable gratification of the educated eye must be the measure of such perfection.

"Centuries of experiment and study have been bestowed upon constructions in stone, baked clay, and wood, and certain ideals of beauty and fitness have been thereby developed suitable for such constructions. But the attempt to apply such ideals to constructions in iron or steel must result in error. The form which is beautiful and fit for the old materials will not necessarily be beautiful or fit for the new materials. Time and repeated experiments must determine the character of the new ideals by which we are to measure and judge the final perfection which apparently we have not yet reached in this department of human endeavor.

"We have all of us, architects and engineers alike, repeatedly committed the same faults which are evident in the interesting example which you represent. Therefore, the critic must present his strictures with becoming humility. I have simply stated the truth as I understand it, and I am very sure that your intelligence will receive it in good part."

Mr. Cummings' letter was as follows:

"I find the questions which you ask me rather difficult to answer categorically. I quite agree with you that as a rule the engineering structures which we are accustomed to see are unsightly and often hideous. I have in mind, at this moment, certain iron bridges in my own city, in prominent and most conspicuous positions, which are an offense to the eye and to the taste of thousands, so aggravated that I have often thought that every structure of the kind ought to be sub-

mitted to a competent commission for approval or rejection before being carried into execution. Mr. Waddell.

"Certainly an elevated railroad is generally an extreme instance of deformity, and every attempt to ameliorate its ugliness deserves to be welcomed and commended.

"Yet, if I am to speak frankly of the design concerning which you have asked my opinion, I must say that I do not feel that you have treated the subject in the best way. Your design would certainly conceal the rough features of the iron construction—the girders, the Z-bars, the struts, the rivet heads and the like—but the concealment is effected by covering them with an imitation of the forms of an architectural construction in stone, of which the decoration is drawn from classic examples. It is here that I conceive you to be working on a wrong theory.

"I do not believe in borrowing architectural forms and applying them to the service of an engineering construction. I have never seen an instance where such an application seemed to me successful; and fortunately such a violation of the principles of decoration is not necessary. Every species of construction is capable of being made comely if not actually beautiful, without any concealment or denial of its materials or its methods. If the great engineering structures have so far failed to bear out this assertion, it is because the engineers in the first instance, and in the second those for whom their structures are designed, have not yet felt the importance of making them attractive to the eye.

"It would perhaps be asking too much of a profession whose work is of so strenuous and practical a cast as that of the engineer that he shall receive the training of an architect in design, but I think it not only entirely practicable, but entirely desirable and important that our schools of engineering should take some account of the possibility of so treating a problem of construction, whether of steel or stone, as to remove as far as may be done the reproach of ugliness and coarseness from the great structures which are one of the most conspicuous and most characteristic features of our later civilization."

Messrs. Carrère and Hastings wrote:

"We beg to acknowledge the receipt of your letter of April 20th, with which you sent us extracts from a discussion on a paper which you read, treating of elevated railroads, and in which you ask for an expression of opinion.

"We feel very much complimented at being asked to advise you in this matter, treating, as it does, a subject which has always interested us very much.

"In general, engineering works do not aim at beauty, and we think that this is always a great misfortune—whether the work be important, as in the case of a municipal bridge, or whether it be trifling, as in the case of small railroad bridges. Any engineering work is a spot in the landscape, or in the city, which has either a good or bad influence on the general appearance of the panorama, and upon its enjoyment.

"The fact that the first aim of every work of engineering is practical, that the essential qualities are strength, simplicity, and economy of cost and of operation, lead many very able engineers to the conclusion that they fail in these qualities in the degree in which they may be artistic; and for this reason many of them are not only indifferent, but are opposed to having their work beautiful. This is probably due

Mr. Waddell. to a misapprehension on their part of the elements required to make such a work beautiful, and perhaps also, to the fact that the usual way of attempting this solution is so often irrational, and seldom, if ever, successful.

"It is, of course, a very desirable thing to consult a skilled architect as to matters of detail, such as ornamentation, the railing of a bridge, candelabras and other small details, which, if successfully designed, may add to the general interest of the bridge; but no amount of ornamentation can possibly add artistic interest to an engineering work unless the conception itself is artistic. In fact, ornament should be used very sparingly, and in an entirely subordinate manner.

"We believe that the great difficulty is due to the fact that engineers, not having been trained in matters of art, do not conceive or plan their structures artistically. They should seek the advice of the skilled architect at the very start, so that the entire work may be designed and constructed on artistic lines, which may even make the use of ornament absolutely unnecessary, or may make it of so little importance that it may be almost bad, and the structure still be beautiful.

"An iron structure, be it bridge, elevated railway or other, must be perfectly simple and rational in its construction; the material must always be used so as to express its individual character, and not try, either in its arrangement, proportions, or details, to assume to represent the use, proportions, or forms of another material; the columns should be only as big as necessary to carry the weight; the beams or girders only as big as necessary for the spans; and the ornamentation should be so designed as to be characteristic of the material and of the process through which it is obtained, whether cast, wrought or otherwise.

"In the case of an elevated railway, the conception is inartistic, as well as irrational. There is no logical or artistic reason for encumbering a street or avenue, or other highway, with a purely utilitarian structure such as an elevated railway. It destroys the outlook and the light, and in every possible way the enjoyment of the street or abutting property, as also the original purpose of the street; and it has no *raison d'etre*, excepting either the rapacity of the corporation which occupies the street in preference to buying its right of way, or perhaps the necessity for having it there as the lesser of two evils, whether ugly or not, where the right-of-way is not otherwise obtainable.

"The thing, therefore, that makes an elevated railway inartistic is the very conception of the idea, and not the execution of it. We do not believe that it would be judicious to have, as it were, a structure decorated throughout; but whatever is done to make an elevated railway more sightly will have to be accomplished by designing it in the simplest and most straightforward way, so that the purely utilitarian portion of it will seem as natural, simple and graceful as possible, and in contrast to the purely utilitarian mass of the structure, by devoting some attention to the frequently occurring stations, and, where possible, by breaking the monotony by an artistic treatment, such as a viaduct, or the introduction of masonry or other features which may lend interest to these particular spots.

"We sincerely hope that you will succeed in convincing your fellow engineers that they have just as much need of the co-operation of the skilled architect in all of their work of this character, as has the skilled architect of the co-operation of the engineer in his work. As

Mr. Waddell.

both works, that of the engineer and that of the architect, partake both of the useful, the true and the beautiful, it seems indispensable that there should be co-operation between the architect and the engineer and between the engineer and the architect, as the case may be."

As the opinions of the three architectural authorities referred to are entirely in accord on the question submitted, there is nothing for the author to do but acquiesce gracefully in their decision and acknowledge that his design for "an elevated railroad for a large city where expense is no object and where appearance is the great desideratum" is not a success, but a violation of true art.

Far, however, from regretting that he introduced the design as a conclusion to his paper, the author is very glad indeed that he thought of so doing, for the reason that the remarks of the architectural authorities just quoted may have the effect of inducing engineers engaged in the designing of structural metalwork to pay in future more attention to the important question of architectural effect in their constructions.

The author desires to express here his hearty thanks to Messrs. Van Brunt, Cummings, and Carrère and Hastings for their courtesy in complying with his request to decide this question of æsthetics.

As Mr. Van Brunt points out, steel construction is a modern innovation, and consequently no attention worth mentioning has yet been paid to the development of artistic features in its designing, for engineers have been influenced mainly by utilitarian and economic motives. If the old ideals of grace and beauty that pertain to constructions in wood and stone are inapplicable to steel, it is now in order to establish new ideals that will apply thereto; and, as engineers in general have been too devoted to utility and economy to train themselves in the artistic, it would be eminently proper for some architect, who is posted in the designing of metalwork and cognizant of the fundamental principles which guide the structural engineer in his designs, and who is an authority upon æsthetics in his own line of construction, to make a special study of the subject of the architectural features of steel bridges, viaducts and elevated railroads, then write for the American Society of Civil Engineers an exhaustive paper thereon, from which and from the subsequent discussions could be established principles governing from an artistic point of view the designing of all classes of steel structures.

In bringing this *résumé* to a close, it is proper for the author to point out in what particulars he would change his plans and specifications for the Chicago elevated railroads in view of the criticisms made in the discussions, were the said plans and specifications to be redrawn.

First.—He would reduce the ultimate strength for basic medium steel 2 000 or perhaps even 3 000 lbs.

Mr. Waddell.

Second.—He would use carbon primer as the first coat of paint, and would endeavor to have it applied at the mills before the metal could be exposed to the weather.

Third.—He would consider very carefully and thoroughly the question of the advisability of omitting on tangents either the outer or the inner guard rails.

Fourth.—He would raise the top flanges of the longitudinal girders about 4 ins. above those of the cross-girders, and block up on the latter with buckled plates to receive the ties.

APPENDIX.—DATA RELATING TO VULCANIZED TIMBER.

"NEW YORK, April 4th, 1895.

"*Editor Railway World:*

"DEAR SIR,—A year or so ago much attention was given by railway journals, people who have to do with maintenance of way, and inventors, to the matter of ties for the road-bed. Columns in papers and many pamphlets were filled with articles on metal and glass ties. Little or no attention was bestowed on the plain every-day timber which has always been with us.

"Recently nothing has been said of would-be substitute ties. Is this caused by the failure of the experiments with the substitutes, or is it that better results have been obtained from the timber?

"I am inclined to the latter belief, and in support of the same offer the experience we have had with track timber on the Manhattan elevated system in New York City.

"When constructed, the elevated roads were equipped with 5-in. x 6-in. x 8-ft. yellow pine ties planed on all sides. The timber was of the best quality obtainable. It was not long before we discovered the ties suffering from decay. To the surface railroad man this may appear strange, considering that our ties are laid on iron girders. We have, however, many peculiar conditions to confront, and the cost of tie renewals was a very serious item of expense.

"To find a remedy for this and reduce what was beginning to be an immense maintenance-of-way charge, many preservative processes were tried, but none seemed to do the work until vulcanizing the timber was used. This process was first tried ten years ago, when we put in two sections of 6-in. x 8-in. x 8-ft. ties; one section of vulcanized timber and the other section of untreated material. It was not a great while until decay began on the untreated ties, while those vulcanized are still in service as good as when first laid. * * *

"Respectfully yours,

"(Signed) R. BLACK, *Roadmaster.*"

The following are extracts from a report which is certified to by the same Mr. Black:

"Agreeable to appointment, Messrs. F. Holbein, F. M. Grumbacher and Daniel Meyers met Mr. R. Black, roadmaster of the Manhattan Railway, at his headquarters at South Ferry station, on May 3d, at 1 o'clock.

"Mr. Black, who has been with the road since 1869, called attention to half a tie, not vulcanized, that had been in use five years.

That portion of the tie where the rail had laid, and where iron bolts had been used, was very badly decayed, but the space between the rails showed no signs of decay. Mr. Black stated that vulcanized wood was not in the least affected by contact with the rail or bolts or metal surface, but that it seems proof against indentation by wear and friction, or pounding of the rail. Mr. Waddell.

"The party was then conducted over the line of the Third Avenue Elevated, in order to be shown a comparison between vulcanized and unvulcanized wood in actual use on the structure. The first stop was at Chatham Square Station, where special attention was called to the condition of the natural yellow pine laid in 1886 on both City Hall and South Ferry branches. It was very much decayed and some portions so soft that it could be pierced with the end of an umbrella. It was a very rainy day and the timber was thoroughly soaked. This timber, Mr. Black remarked, was being replaced as rapidly as possible with vulcanized wood.

"Our second stop was at the Grand Street Station, where vulcanized ties and guard rails laid in 1883 were examined. This vulcanized timber was found in as sound condition as when first laid. Mr. Black called attention especially to guard rails which he had bolted together in 1883, the inside rail vulcanized and the outside rail not vulcanized, in order to have both subject to precisely the same conditions in every particular, and to afford opportunity for comparison in later years. The vulcanized was as sound as when laid. The part not vulcanized was in a decayed, punky condition. Attention was called to the vulcanized flooring on the station platform. He stated that they formerly used tongued and grooved lumber, but now they used vulcanized slatting without tongue or groove, as it kept its place without warping or shrinking, although exposed to cold, rain and sun.

"The next examination was at One Hundred and Sixteenth Street. Ties not vulcanized, which were laid five years ago, were all being removed because of their decayed condition, and were being replaced by vulcanized ties."

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"Mr. Black stated that about four and one-half miles of creosoted ties were now in use on the suburban branch and called attention to the soft, spongy character of creosoted wood, that the iron plates supporting the ties were deeply imbedded in the wood, and that it was difficult to keep the spikes in place, especially on curves. Extra appliances had been used to keep the rail in place. He also stated that during the hot season, when the temperature changed during the day from 40° to 95° Fahrenheit, causing expansion of the rail, spikes near the center of the rail would be lifted out of place from creosoted ties. He also stated that these ties were of yellow pine and the very best quality of creosoting, but that their experience was such that no more creosoted timber would be used, as vulcanized timber gave much better satisfaction; besides it does not affect the hands and faces of the workmen who handle it as creosoted timber does."

The following is a copy of a letter directed to Colonel S. E. Haskin, under date of March 1st, 1889:

"In replying to your enquiries as to the life of the cross-ties and planking which has been treated by the vulcanizing process, which we placed on the structure six years ago this month, I have to say, timber is sound and the surface of the ties and planking very hard.

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"There are no indications of decay at the end of those planks which were vulcanized, while the planks not treated and placed on the structure about the same time are decayed at the ends, or where they are nailed to the supporting timbers.

"I am inclined to think the process of vulcanizing will soon be found to be the best way of preserving timber.

Very respectfully yours,

(Signed) ROB'T I. SLOAN, *Chief Engineer.*"

The following is a copy of a letter to the Haskin Wood Vulcanizing Company, under date of March 28th, 1891:

"In replying to your enquiry regarding my opinion upon your process of vulcanizing for the purpose of preserving wood from decay, etc., and especially with reference to the yellow pine railroad ties, which were treated by your company's process, and laid in the tracks of the switchyard of this company in the spring of 1884, having been in constant use and exposed to the full action of the elements, and subjected to extraordinary wear and tear, I have to say that, on the 6th day of March, 1891, I had two of said ties taken up for the purpose of making an examination of their condition, and was much surprised to find them in a perfect state of preservation, and practically as good as new ties, so far as wear was concerned, the spikes having held firmly, as they were originally driven.

"During my experience in the railroad business of over forty years, during which time I have used all kinds of timber in railroad work, and have tried the various kinds of treatment for the preservation of timber from decay, I am free to state that I have never found any method that has shown such a satisfactory result; and I believe your process of vulcanizing will increase the durability of timber at least 50 per cent.

"The remaining ties, which were treated by your company's process, are in the same place as they were first laid, and from present indications they seem good for seven years' more service.

"In conclusion, I would say that I think it would be to the interest of any company using timber, which is exposed to the elements, to at least give this process a trial, as they could not fail to be convinced of its effectiveness.

Yours respectfully,

(Signed) ROB'T WHITE, *Supervisor of Tracks and Repairs.*"

Mr. White wrote also to the same parties, under date of April 6th, 1891, as follows:

"Replying to your question as to the life of yellow pine ties, will say that, when used in the switchyard of this company, in their natural state, and exposed to the full action of the elements, they last, on an average, three years, during which time they have to be turned.

"The ties treated by your company's process of vulcanizing, and which were laid in the tracks of this yard in the spring of 1884, are perfectly sound, and have not been turned or respiked since they were laid."

The following is the *résumé* of a report to Colonel Samuel E. Haskin, under date of November 26th, 1894, by Mr. Alfred P. Trautwein, who had made a series of comparative tests on vulcanized and untreated yellow pine timber on the testing machines of the Stevens Institute, Hoboken.

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"These experiments show the following average results.

"Modulus of rupture:	Untreated wood.....	10 762
" "	Vulcanized "	13 098
" elasticity:	Untreated "	877 098
" "	Vulcanized "	1 054 941

"These experiments, of course, were not numerous enough to determine exactly how much vulcanizing affects the wood, but they establish the general fact that so far from weakening the wood, the process of 'vulcanizing' seems to strengthen it; the modulus of rupture by transverse stress being 21 per cent. higher. The crushing strength was increased 23 per cent.

The author has been informed that the Hon. B. F. Tracy, ex-Secretary of the Navy, with a view of adopting vulcanized wood in naval construction, appointed a special committee which visited the vulcanizing works in New York, and, after an exhaustive investigation, reported that vulcanizing increases the strength and durability of timber, and recommended that vulcanized yellow pine be used for backing in one of the monitors. Their tests showed that vulcanizing increases the strength of yellow pine 18%, and decreases the deflection over 13 per cent.

The following is a copy of a report to Mr. A. Bevier, General Manager New York Wood Vulcanizing Company, by J. A. Deghuee, Ph. D., Chief Chemist of the Pure Food Department of New York City, under date of January 29th, 1897:

"As to the result of the various tests made of your vulcanizing process; in order to condense it I will confine it to samples A and X. This will show you all the practical conditions of the changes brought about by your process.

"The piece of wood A was just twice the size originally of the piece I returned to you. The other half was cut up into fine shavings and the extractive matter dissolved out by cold ether, the contents being in bottle A. This piece of wood had been vulcanized by your process.

"Block marked X, untreated yellow pine, was also cut up and the extractive matter dissolved out by cold ether, contents being in bottle marked X. This block was also twice the size originally of the piece returned to you.

"The vulcanized extract in bottle A shows a mixture of resinous acids, together with a number of bodies similar to those in wood tar creosote, all of which have strongly antiseptic properties.

"By your process nothing escapes but the free water. The amount that can be extracted from the wood will vary in keeping with the character of it, *i. e.*, from a rich, resinous wood more can be extracted than from a lean porous wood. You will extract as much from vulcanized wood as can be extracted from untreated wood, nothing escaping in the process except water, and the amount will vary with the original condition of the wood. I do not believe that the strength of the wood is impaired in the least by your treatment; but on the contrary, the diffusion of the resins and other liquefiable matters throughout the wood, thereby adhering to the fiber, would

Mr. Waddell. have a tendency to solidify the contents and increase the strength. However, this is a mechanical question which can be determined by tests at Columbia College and Stevens Institute, where they have apparatus for making such tests.

"Besides the changing of the extractive matters into an antiseptic, you also coagulate the albumen, which has a tendency to seal up the pores.

"There is another benefit by your process which I think equally as important as the creating of an antiseptic and the coagulation of the albumen, and that is sterilizing the wood; and there is no doubt in my mind that from the amount of heat used, this is thoroughly done. In all wood there is living matter carried throughout it by the flow of sap; either living matter or spores which produce the same. This hatching, as you may term it, is brought about by heat and moisture and develops the spores into mould which eats the wood and produces what is known as dry rot. Decay is due to living matter and in order to produce decay in your process, the living matter will have to enter from the outside.

"By the creosoting process in some cases resin is mixed with the creosote to prevent solubility, and by your process I consider that you are accomplishing the same result. Your process also produces the same results to the very heart of the wood as are produced upon the surface. If the timber was of the quality of sample A, in my opinion you would create from 190 to 200 lbs. of antiseptic matter to a thousand feet board measure. I arrive at this conclusion from your statement that the average weight of yellow pine, such as sample A, is about 4 000 lbs. to a thousand feet board measure. The condition of the wood in your treatment would not be changed by the separating or splitting of the timber, as the treatment goes throughout, thereby leaving no exposed surface."

The author regrets the necessity for occupying so much of his *résumé* with testimonials as to the merits of vulcanized timber; but, as Mr. Belknap has asked for such data and tests, he cannot well avoid giving them.